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TRANSACTIONS
OF THE
AMERICAN INSTITUTE
OF
ELECTRICAL ENGINEERS.

GENERAL MEETING, MAY 21ST, 1890.

SUBJECTS:

Electric Lighting in the Tropics.
BY WILFRID H. FLEMING.

Life and Efficiency of Arc Light Carbons.
BY LOUIS B. MARKS.

Practical Aspects of the Alternating Current Theory.
BY M. I. PUPIN.

Magnetic Data of the Sprague Street Car Motor.
BY H. F. PARSHALL.

The Industrial Utilization of the Counter Electromotive Force of Self-Induction.
BY THOMAS D. LOCKWOOD.

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AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

At the meeting of the Council, June 17th, 1890, the following preamble and resolutions were unanimously adopted.

Whereas, Mr. T. C. Martin having been a member of this Board for the past six years continuously, in the various capacities of Secretary, Manager, President and Vice-President, and

Whereas, during the whole of that period he has devoted himself to the affairs of the Institute with unremitting zeal and fidelity,

Resolved, that the council, upon his retirement from office, and in recognition of his valuable services, hereby tender to him their heartiest thanks and good wishes, coupled with the assurance of their warmest esteem ; and

Resolved, that this resolution be printed in the transactions of the Institute, and that the Secretary forward a copy to Mr. Martin.

GENERAL MEETING AT THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

MAY 21ST, 1890.

MR. R W. POPE called the meeting to order and said:

Gentlemen, we are assembled here under the auspices of the Massachusetts Institute of Technology, of which General Walker is the distinguished President, and I have the honor of announcing that he will now give you a brief address of welcome.

GENERAL WALKER:—Mr. President and Gentlemen of the American Institute of Electrical Engineers: It gives me very much pleasure, on behalf of the corporation and faculty of the Institute of Technology, to welcome you to these halls. We feel it to be a great privilege to receive on this occasion a body of men so justly and widely distinguished for their acquirements and for their positive contributions to knowledge. We trust that you will make yourself entirely at home in these buildings, which are dedicated to industrial science, and to the promotion of the useful arts, and whatever we, on our part shall be able to do toward the pleasure and practical success of your meeting, will be done most thoroughly and most gladly. We have on previous occasions been permitted to receive here the American Society of Mechanical Engineers and the American Society of Mining Engineers, and in each instance we felt this to be a high privilege. Not only our Faculty but our students have derived great inspiration from these gatherings. I know of nothing that can give a stronger impulse to generous young men pursuing laborious courses of study, than to see those who have already distinguished themselves in the professions to which they aspire going familiarly in and out among them and hearing them participate in debate on subjects of practical present interest to the profession For our students' sake, therefore, as well as for our own pleasure and instruction, we welcome you most heartily to the Institute of Technology. Especially are we gratified that the present occasion gathers here the recognized leaders in that department of thought and research on which is concentrated so much of the scientific and practical interest of to-day. You, gentlemen, are dealing with that mighty and mysterious force to which the whole world is looking for the solution of many of the most serious difficulties and perplexities of life, for a generous enlargement of the sphere of human power and for triumphs greater far than man has yet achieved in his unceasing struggle with the material conditions of existence. Already nearly one hundred of our most earnest students are striving with unstinted labor and pains to qualify themselves to become your juniors and colleagues, and in time your successors in the exalted profession which you so fitly represent.

Right happy am I, Mr. President, that I may address these we coming remarks to one on whom the laurels of peaceful triumphs have been heaped almost beyond the privilege of the greatest inventive minds of history. (Applause). Of these you may rightfully be more proud than ever conqueror was of the spoils of war and the trophies of bloody victory. In the name and on behalf of the Institute which I represent, I congratulate you, sir, on the splendor of your achievements and on the purity of your well-earned fame. And again, with all my heart, I bid you and your honored Association welcome to the Institute of Technology. (Applause).

PROF. THOMSON:—Gentlemen of the Institute: It is surely beyond my power to respond to the sincere welcome which we have received at the hands of the Massachusetts Institute as gracefully as General Walker has extended it. The Institute, of course, is well known to you. It is an Institution which has turned out very many of the leading engineers of the country, and to-day it is contributing its share to our profession, and in fact I may say a very large share. I have reason to know that the training which is given here at the Institute is of the greatest value in fitting young men to take up the practical work of engineering. It is, therefore, fitting that the Institute of Electrical Engineers should make its headquarters here. I need not enlarge on the facilities possessed by the Institute of Technology for demonstrations. We shall probably see later that if our papers need illustrating, we can be supplied here with experimental arrangements. And I may add further that I have a sort of sympathy with General Walker in the welcome which he has so cordially given from the fact that our headquarters are in this vicinity and I may say that I also welcome the members of the Institute just as sincerely to Boston and its surroundings. We hope to be able to make the stay of the Institute as pleasant as may be during the course of this meeting. I have nothing further to say, except that we are very thankful, and I have no doubt that every member will say that he is very thankful for the opportunities here offered and for the hearty welcome that General Walker has given us.

In opening the meeting I will state that the Secretary has some announcements which he desires to make.

THE SECRETARY:—Mr. President, it may interest those of the members who were not present at the business meeting held in New York last evening, to be informed that the following gentlemen were elected to fill the vacancies caused by the expiration of the terms of the officers as named in the programme.

For President, Professor W. A. Anthony, of Manchester, Connecticut; for Vice-Presidents, Francis B. Crocker, Joseph Wetzler, Frank J. Sprague; for Managers, H. Ward Leonard, P. B. Delany, H. A. Foster, J. C. Chamberlain; for Treasurer, George M. Phelps; for Secretary, R. W. Pope.

To-morrow's work will be play. It is to be devoted, if we pass through our programme successfully to-day, as we hope to do, to a trip which the West End Railway Company will arrange over its line, and a visit to the new Power Station in the forenoon, and in the afternoon a trip will be taken to the Thomson-Houston factories, which will be opened to the inspection of our members, and under suitable escort, so that everything we trust will pass very agreeably, as such affairs usually do in this city.

The dinner at the Boston Electric Club this evening will take place at 6.30 and it is desirable that the members assemble at the Parker House promptly. The reception rooms will be opened before that time, and the members of the Institute who have announced to the Secretary that they will be present at the dinner will find their places assigned to them, and their names at the plate.

The diagram of the table will be ready for examination in the reception room. There will be about 200 present.

The programme of papers will be changed slightly. The paper of Mr. Marks will be taken up this forenoon, and the one on a

New Photometer, by Doctor Nichols, will be read at the afternoon session. This change is made to accommodate Mr. Marks, who has an important engagement elsewhere.

I notice among the audience our newly elected President, and I trust he will come forward now, as is the custom, and take the chair.

On account of President Anthony's recent indisposition he does not feel quite able to assume the duties of the chair this morning.

The first paper on the docket is Electric Lighting in the Tropics, by Wilfrid H. Fleming of New York City. In the absence of Mr. Fleming, Mr. Wetzler will present this paper.

Mr. Wetzler read the paper.

A paper read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.

ELECTRIC LIGHTING IN THE TROPICS.

BY WILFRID H. FLEMING.

One of the chief difficulties that an engineer experiences who is called upon to install a plant of any considerable size in tropical countries is the trouble of procuring any kind of skilled labor for this particular class of work. Another difficulty is that he is so far from his base of operations—the factory—which will often lead him to depend upon himself in overcoming obstacles that arise from time to time as the work progresses. Language and the heat, as well as fevers, are minor affairs.

Electric lighting has already gained many warm adherents both in the East and West Indies, more especially in the former where plants of considerable capacity have been in active operation for the past eight years. It is especially adapted for use in houses in warm climates, such as that of India, where the old-fashioned "punkah" is in daily and nightly use for cooling the rooms, accompanied with its attendant noise as the "punkah wallah," a servant pulls it backward and forward causing the continual flickering of the lamps or gas. That system will, in time, I hope, give place to the noiseless motor fans and steady incandescents, thus enabling the Anglo-Indian to read and rest in comfort.

A central station plant that the writer was engaged upon lately in one of the chief cities of the West Indies, would compare favorably in size and equipment with one situated in a city of a corresponding number of inhabitants in the United States. Alternating current dynamos of a capacity of 4.500 16 c. p. lamps were employed for lighting the chief stores, theatres and private houses, and 600 arc lights of 1200 c. p. each lighted up the main streets and parks.

It was at first intended to run a small plant in connection with the existing gas works, more as an experiment than with a view to actual financial success, but in the space of six months the station was more than trebled from its original capacity.

The people took to it from the start, paying cheerfully the prices that were demanded. To an indolent race it was a great boon. Money to them, it would appear, was of less account than the trouble and work called upon to go around and light up the different oil and gas lamps, since all the lights were switched on the different circuits at sunset. In the tropics, as is well known, there is no twilight. Darkness comes on within 10 minutes of sundown and the whole plant practically goes into operation at once.

The construction work on this particular plant was necessarily somewhat slow, as men unaccustomed to erect a 30 or 45-foot pole took their time to do so, in which operation they received the appreciation of the usual army of idlers. Poles suitable for carrying a number of circuits had to be imported from the United States, as well as the ornamental wooden columns for supporting the lamps in the parks and public squares. Poles of native growth could not be found straight enough and even if of sufficient length were weak. Some poles could have been had from a tree called the iron wood tree. This wood, however, is of so close a grain and so very heavy that it was out of the question to use it. Many of the business streets were not more than from 20 to 30 feet across including the sidewalks. Moreover, as curtains or awnings are stretched overhead from side to side by the owners of the stores to shelter and protect their goods from the sun's rays, it was impossible to erect a pole line down these streets, I found it better to run a two-inch iron piping up the side of the houses every 150 feet to a point 6 feet above the coping stone, and then attaching to the top of this pipe a **T**, inserting in this **T** wooden cross arms to which the insulators were attached in the usual manner. It must be borne in mind that the houses are not of very great height. Where this arrangement was impracticable owing to the varying heights of the houses, I inserted strong iron brackets in the buildings set in with cement and well painted with rust-proof paint.

In India considerable care has to be exercised in putting up a pole line. If you want your work to stand any length of time, the base of the poles for one-sixth of their length must be thoroughly well creosoted to resist as far as possible the ravages of an insect called the white ant or "termite." These insects live on wood. They attack even the wood-work of the houses and soon reduce the thickest timber to a mere shell. They live in trees and construct nests of great size like small sugar casks made of particles of gnawed wood and cemented by a kind of gluten. They are so strongly attached to the branches that they cannot be shaken down even by violent storms. It is a good plan to paint the poles 8 feet above the surface of the ground with good gas tar if obtainable. In these climates special attention should be given to protecting the working parts of arc lamps, owing to the fact that rain occurs only for about three months of the year and to make up for this loss, the humidity of the atmosphere is remarkable. It is not at all infrequent to find early in the morning the bottom carbon holders full of water unless provision is made for draining this off. During the hot season, a breeze springs up between 9 and 10 o'clock in the morning and the ground being dry, the dust is terrific. Insects of a large size —much more so than those found in the northern climates— bats and small birds attracted by the glare are found either in the globes or lying at the base of the lamp posts in large quantities every morning; and the wholesale slaughter that takes place nightly seems to have no effect in diminishing these pests.

It was found better, therefore, on the arc service to give a man about 25 lamps to trim and clean per day, and the native entrusted with this work was held responsible and if the lamps were found in a dirty condition he was fined, which usually had a good effect.

In the construction of station buildings one is guided much by the facilities for procuring stone brick or other suitable material in that particular locality. Galvanized iron is sometimes used for roofing, but more frequently roofs are constructed of a sun-baked clay tile, provision being made as is usual for an ordinary wire tower for distributing the various circuits. A point to be noted is that the engineer should construct his rain gutters for taking off the storm water at least double the size that is ordinarily allowed for temperate climates. Roofs and the outsides of the buildings are white-washed.

To give an idea of the heat from the sun, I may mention that I had to replace considerable quantities of insulated wire after it had been up only a short time, the insulation in places sagging right away from the copper wire and finally dropping off.

During the rainy season prevailing in the West Indies in the months of June, July and August; and in the East Indies, known by the name of the south west monsoon, and prevailing from May to the latter part of August, electrical storms occur almost daily. They are often exceptional in violence, and much trouble and anxiety arises from possible damage to line, lamps, and dynamos, even though protected by good lightning arresters.

While a heavy storm was in progress one night last summer in the West Indies, I noticed when in the station a curious effect of a flash that fused the lead strips on an ordinary saw-tooth arrester connected with one of the incandescent circuits. The strips were entirely destroyed or volatilized and what was before a polished plate of brass was now tarnished with a film of the lead vapor, and there was distinctly marked as if photographed on the plate a zig-zag streak, in all appearance like a photograph that had been taken of lightning. Engineers, during the prevailing season of storms, should take particular pains that their lines and machines are thoroughly well protected and that the arresters have good earth connections.

A sad case came under my notice that happened at a temporary installation for illuminating a camp in Poonah, in the Bombay Presidency, with arc lamps in honor of a visit of an influential Rajah. Whilst the festivities were taking place in the evening, a heavy storm occurred. Lightning entered on the line, no provision had been made for diverting its course, and it destroyed the dynamo besides killing the native oiler who just at that moment was engaged in filling up the oil cups on the bearings. He was either thrown or fell across the commutator end of the dynamo, as he was found in that position, his hands much burnt as well as his feet.

In the year 1877 the first commercial arc lamp was in use at the offices of the Bombay *Times*, and if I remember correctly it was the first light shown in the Indian Empire. From that date on, the demand for lighting has been on the increase; but pretty nearly all the work has been confined to isolated work and small central stations, cotton mills, sugar and indigo plantations, government buildings and large private dwelling houses. Places of business and offices do not require lighting, as business is conducted by the merchants only from 7 o'clock in the morning till 4 in the afternoon. The inhabitants of hot climates necessarily spend much of their time out of doors and are fond of social gaiety. They have been famous for centuries for skill in illuminating, and this fact has added much to the popularity of arc and incandescent lamps, which as is well-known, particularly lend themselves to artistic illuminating purposes. From this knowledge, in the early part of the year 1885, I imagined that it would be a financial success to get together a travelling portable electric light plant, consisting of a vertical boiler, engine and two dynamos, one an 8 arc light machine and the other a 100 light incandescent, both mounted on a stout frame which rested on a pair of bisel trucks. This work was carried out, and I was kept actively employed for many months in going round to different large Indian estates and native palaces for the fetes that attend the various religious and family ceremonies that the wealthy natives are fond of indulging in. Large sums of money are spent and the festivities often last for a week or longer. It turned out to be as I surmised it would, a regular "bonanza," until on one occasion in bringing the unwieldly contrivance down a steep hill on one side of which was a ravine, it fell over; and it is needless to relate, that the whole apparatus was seriously damaged. I found it would not pay to patch it up again, so after stripping everything that was portable I left the remainder to lie and rust in the tropical vegetation.

Owing to the high price of coal, which is a costly article in the tropics, ranging from $8 to $50 per ton delivered, it is well to employ the most efficient and economical engine for motive power, more especially for central station work. In the station previously referred to, we were running with high speed compound condensing engines with satisfactory results.

In many sugar plantations in the West Indies where the installations are of a comparatively small size, economy in this direction is not practised as the amount of steam used is not missed, the boiler capacity on estates ranging from 100 H. P., to one at Cienfuegos, Cuba, of 2,500 H. P. It behooves the engineer, however, who has charge of a plant to exercise considerable care and watchfulness over his native firemen. The natives, as a rule, I have found, if treated with kindness and forbearance, show an aptitude in learning and taking hold that is often remarkable, more so than with some of their brethren of a lighter color who because they have been taught how to start and stop a dynamo or trim an arc lamp, give themselves all the airs of an expert in electrical matters, and have got beyond that stage when they are willing to be instructed or to be obedient to orders, an unwillingness that sometimes leads to disastrous results.

The types of machines chiefly in use in the East Indies are those of English and French manufacturers, Siemens, Gramme, Silvertown and other well-known types. Those in use in the West Indies and South and Central America are generally of American make, and the market is not a small one. The great strides that both the foreign and home companies have made in the last two or three years in the supply and equipment of electrical plants for these distant lands are very evident signs that this particular business is receiving great attention at the hands of local merchants, planters and city or town officials and that they are more and more influenced by the many advantages to be gained by the use of electric lighting. Planters find now that it is much to their gain in a financial way. In former years, for example, the facilities of shipping their produce were restricted, and the work was done in daylight and slowly. Now with weekly and almost daily sailings, it is an absolute necessity that they should get their produce ready with the quickest despatch possible, and this they do with the aid of the electric light. When an engineer is called upon to install or take charge of an electric light plant, it will be well for him to insist pretty closely not only that all the materials specified in the estimates have been shipped, but that every class of tool requisite for constructional work is included. Much time is lost and much trouble is made when you find that your outfit does not include "climbing spurs" or draw vises and other important articles. I have known engineers who have had expensive testing sets, Wheatstone bridges, reflecting galvanometers and other delicate instruments sent out with them, and then found that they had few or any tools to work with, and that the nearest hardware store was many miles away through a rough country, and even then, the store when reached did not contain the requisite goods, there having been no stock kept because there was no demand made for them. Spare armatures, complete sets of arc lamp apparatus as well as duplicate parts of dynamos, spare brasses and gear for engines and tubes for boilers should always be included and it should be seen that they are shipped.

Apart from the vicissitudes incidental to life in the tropics, there is, I think, always a satisfaction and pleasure in the successful completion of an installation, knowing as one does that it is a potent factor in the greater civilization of those countries, demonstrating to the inhabitants, who have heretofore depended on artificial illumination of the same primitive character and manner as their forefathers used through ages past, what science aided by her lieutenants "pluck and energy" can accomplish.

DISCUSSION.

PROF. THOMSON:—Gentlemen of the Institute, you have heard the very interesting paper read and it is now open for discussion. Any remarks or additions to the information given in the paper will be acceptable from any member who has had similar experience.

I would simply say on our own account that we have had at least the effects of some of the difficulties brought home to us in the shape of corrosion in the tropical regions, on the Isthmus and especially in Colon. The wind seems to bear salt spray with it from the Gulf and it deposits this upon everything, so that brass will not live, and even copper will not live. The moisture is so great and probably salty, combined with rank vegetative emissions or effluvia, that corrosion goes on at an inconceivably rapid rate—a rate which is to us altogether unknown. I have seen brass castings partly eaten through, and even copper wire covered with insulation—not of course a very fine insulation—but I have seen the insulation partly intact and the copper wire turned into a green compound until it was nearly corroded away. I have seen lengths of it of several feet. So that we in this climate hardly appreciate the difficulties which are added to the difficulties of getting labor and commanding it as pointed out in the very interesting paper.

Read before the General Meeting of the American Institute of Electrical Engineers, Boston, May 21st, 1890.

LIFE AND EFFICIENCY OF ARC LIGHT CARBONS

BY LOUIS B. MARKS, M. E.

From the experimental stage of arc lighting to the commercial application of the system to-day, little or no increase in the efficiency of the carbon points appears to have been made.

Now that our dynamos and lamps have reached such a state of perfection, the subject presents itself as pre-eminently important. The arc light pencil, considered as an individual part of the plant, is indeed a small thing, but in it undoubtedly lies the weak spot of the system.

It was with a view of studying the action of modern carbon pencils, that the investigations here to be be described were undertaken. The carbons experimented upon were all of American manufacture, and were procured from five companies, (A, B, C, D and E.)

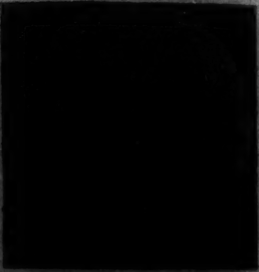
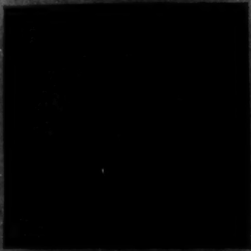
While the greater part of the research was upon the life and efficiency of the pencils, observations were also made in other directions.

The subject will be treated under the following heads:—

1st. Structure of the carbons.
2nd. Life tests.
3rd. Efficiencies.
4th. Candle-power measurements.
5th. Observations of the arc and carbon points.

It is well known that the life and efficiency of a carbon depends upon the system in which the latter is burned. For instance, "the requirement of the low tension system seems to be a carbon that is hard, well plated and a good conductor, the latter being the most important."

"In the high tension system, on the contrary, hardness and conductivity seem to be of secondary importance. There is a

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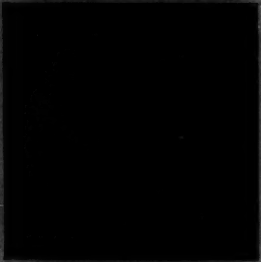
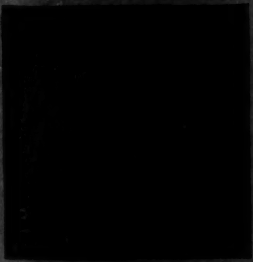

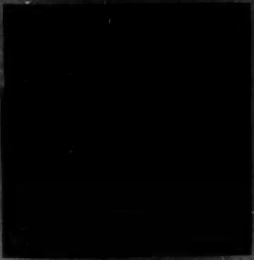

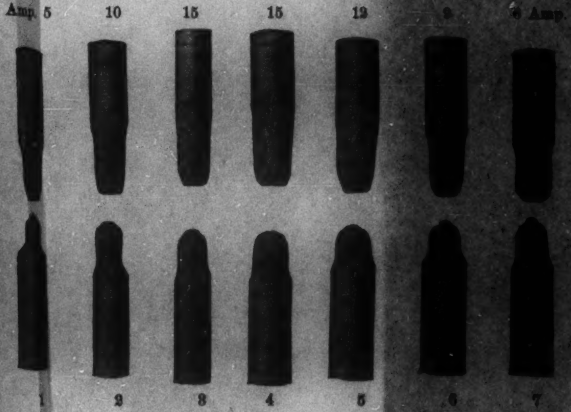
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Fig. 26.

Form of the Carbon Points: Constant Potential—50 volts.

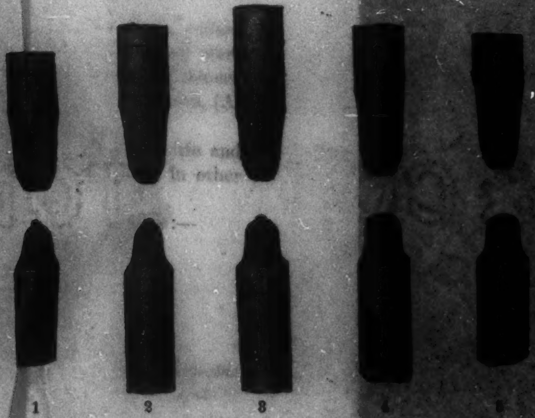

Fig. 27.

Form of the Carbon Points: Constant Current—10 Amperes.

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tendency to 'flame' and burn unsteadily when a hard carbon is used in this system, and a softer one sometimes becomes necessary."[1]

It is interesting to note the methods employed by carbon manufacturers to attain the conditions above mentioned. In one of our largest carbon works, "forced" carbons, or those made by "squirting" the plastic material through a die, are manufactured for both high and low tension systems of lighting, to the exclusion of molded pencils. On the other hand, another company makes no forced carbons, but claims that its molded pencils are superior for either system. From the classification given below, can be seen the types of carbons now upon the market for both systems.

Carbon.	High tension.	Low tension.
A	molded	forced
B	"	molded
C	"	"
D	forced	forced
E	molded forced	"

One of the first things that suggested itself was the study of the structure of the various samples submitted.

For this purpose, thin transverse sections of all the specimens were cut and mounted on glass slides, and a microscopical examination made.

The accompanying photographs (Figs. 1-12) show the appearance of the carbons under a magnifying power of about forty diameters in the case of groups A, B and C, and about eighty diameters in that of D and E. While the views cannot give either the color or lustre of the original, they are mainly useful in conveying an idea of the texture of the surface.

Examining the photographs we note that there is a marked difference between the structure of a molded and a forced carbon In the high tension pencil of the brand A, (Fig. 1) the structure is a loose one, while the low tension rod of the same group is marked by a dense homogeneous structure; the size of the grains of carbon in the latter case is very much less than in the former, and as seen under the magnifying power of the microscope, the particles have a more metalloid lustre. Again there is probably considerable air space in Fig. 1.

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[1] G. W. Parker: Proceedings National Elec. Light Assoc'n, Pittsburgh Convention, Feb., 1888, p. 455.

Thus it appears that Fig. 1 has the qualifications of a high tension carbon, *i. e.* looseness of structure, hence comparative softness and high resistance; and Fig. 2 the requisites of a low tension pencil, *i. e* density, hardness and low resistance. The resistance of the rod (Fig. 1) was measured and found equal to .199 ohm; that of Fig. 2 equalled .144 ohm. The resistance of the plated low tension carbon was .084 ohm.

The structure of the carbons in group B, (Figs 3 and 4) was was found after close examination to be about the same. To secure the requisite low resistance of Fig. 4 the pencil was heavily copper-plated, the thickness of the coating being about 1-10 millimetre, while that of Fig 3 was a little less than 1-20 millimetre.

A method different than either of those just described is used in the manufacture of carbons C, (Figs. 5 and 6.) As in the previous instance, molded carbons are made by this company for both high and low tension systems, but a much greater pressure is applied to the molds in manufacturing low tension pencils than in the case of high. This accounts for the difference in structure exhibited in the photographs; although a molded carbon, Fig. 6 thus approaches the structure of the forced pencil, Fig. 2.

Groups D and E are highly magnified. An attempt has been made to manufacture a carbon that will burn fairly well in either system. Fig. 8 shows this carbon. In structure it is a mean between Fig. 7 and Fig. 9. Besides a difference in pressure used in constructing pencils of group D, there is also a difference in the "mix" or composition of the carbon.

The dissimilarity in structure between carbon E, Fig. 11 and E, Fig. 12 is apparent, yet both pencils are used in high tension systems. The efficiency of these types, as well as of the others will be discussed later. Fig. 12, it will be noted, is very similar in structure to Fig. 9 (carbon D); in both cases the striations are marked and indicate that the carbon is built up of strata lying longitudinally, or in the same direction as the application of the pressure used in manufacturing the pencils. When examined with the microscope, carbon D, (Fig. 9) evinced more lustre than Fig. 12, showing that a greater quantity of pure carbon was used in the manufacture of the former.

LIFE TESTS.

If a carbon is burned with a small current its life will be long at a sacrifice of light-giving properties. If on the other hand a large current is used, there may be a gain in efficiency at a sacrifice of life. The question arises—what is the proper current to use? Of course circumstances determine to a large extent the answer and generally such a current is used as gives a fair mortality at a reasonable efficiency of the carbon.

The high tension carbons submitted for test were designed to be burned at about 10 ampères and the low tension at about 20. In the life tests a Thomson lamp was used for high tension runs, current being kept constant at 10 amperes and P. D. at 50 volts. For low tension carbons the Weston lamp was used. The pencils were accurately weighed before and after the runs, and the life calculated on the assumption that the carbons were homogeneous. Each set of pencils was burned an hour. The results of tests are given in table 1.

TABLE 1.

LIFE TESTS.

CARBON.	Mean Diameter; inches.	Resis. ohms.	Initial wt. + grms.	Initial wt. — grms.	C. amperes.	P. D. volts.	Loss in wt. + grms.	Loss wt. — grms.	Life 12 inch + carbon hours.
A molded high ten. (naked)	.502	.199	59.87	25.10	10.	50	5.86	8.59	10.22
A forced low ten. (plated)	.500	.072	64.89	27.16	21.5	30	6.15	4.43	10.55
B molded high ten. (plated)	.505	.075	58.17	28.32	10.	50	4.80	2.44	12.12
B molded low ten. (plated)	.498	.071	367.80	295.50	22.5	28	166.60	51.50	9.42[2]
C molded high ten. (naked)	.510	.2165	62.94	29.03	10.	50	6.21	3.68	10.13
C molded low ten. (plated)	.515	.0715	594.40	294.50	22.5	28	151.00	41.0	9.83[2]
D forced low ten. (plated)	.506	.095	62.46	36.10	21.5	30	6.92	3.08	9.03
D forced high or low ten. (plated)	.504	.142	60.58	29.78	10.	50	6.65	4.16	9.11
D forced high ten. (naked)	.457	.187	47.20	23.53	10.	50	5.46	3.29	8.64
E forced low ten. (naked)	.505	.2207	344.68	244.64	22.5	28	193.18	74.42	7.71[2]
E molded high ten. (naked)	.533	.202	63.30	30.48	10.	50	6.09	3.04	10.39
E forced low ten. (naked)	.522	.251	59.62	29 81	10.	50	5.91	3.52	10.09

[2] These low tension runs were made with the Weston plant on the University Campus. Ten lamps were run in series. Time of test was 2¼ hours in the case of carbons B and E, and 2 hours and 25 min. in the case of C.

It has been stated that "with carbons of the same *hardness* and length but having different diameters, the larger will undoubtedly outlive the smaller. Of carbons of the same *diameter* and length, but differing in hardness, the harder will outlive the softer."[1]

This statement presupposes that the conductivity of the carbon is directly dependent on the hardness or softness of the pencil.

In order to examine more fully the relation between diameter resistance and mortality of a pencil, six sets of carbons of the brand B., varying in diameter from ½ to 1⅛ inches were carefully weighed, their resistances measured by the Wheatstone Bridge method and the pencils burned with a constant current of 10 amperes from a Gramme dynamo. the P.D. at the terminals of the the lamp being kept at 50 volts. The diameters and resistances respectively of the upper and lower carbons were in each case practically the same. A mean of ten micrometer measurements of the diameter, was taken as correct. The duration of each run was 60 minutes.

Following are the data:

TABLE 2.

MORTALITY WITH DIFFERENT DIAMETERS.

CARBON.	Mean Diameter; inches.	Resis. ohms.	Initial wt. + grms.	Loss wt. + grms.	Life 12 inch + carbon hours,
B molded high ten.	.453	.0805	44.70	4.20	10.64
" "	.505	.075	58.17	4.80	12.12
" "	.618	.0735	94.98	6.96	13.64
" "	.739	.0615	132.34	6.19	21.38
" "	.936	.061	232.20	8.88	26.15
" "	1.195	.059	339.57	10.14	33.49

From the results given in table 2, it appears that the life of a carbon varies *directly* with its *diameter* and *inversely* with its *resistance.* This law holds only for homogeneous carbons of the same manufacture, type and structure, and as stated before, for constant current and voltage.

Let us take the ½ inch (.505″) and 1 inch .986″) pencils as standards and from the relation above stated, calculate the mortality of the other carbons.

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[1] G. W. Parker.

Table 3 gives a comparison of the actual and the calculated life of the various specimens tested.

TABLE 3.

CARBON.	Mean Diam. inches.	Standard—½″ (.505″)	Standard 1″ (.986″)	Actual life hours
		Calculated life hours.	Calculated life hours.	
B molded light.	.453	10.92	9.32	10.64
" "	.618	15.10	13.62	13.64
" "	.739	21.58	19.44	21.38
" "	1.195	36.40	33.04	33.49

Thus it appears that the calculated life throughout the series is larger than the actual when the ½″ carbon is taken as a standard and smaller when the 1″ pencil is made the basis of calculation.

The carbons of group B were not perfectly round, a variation of 3% being at times found, between the ten measurements of the diameter of a pencil. In determining the resistance of the carbon rods, the tips of the latter were copper-plated when necessary and mercurial contacts used. The lamp was adjusted to burn at 50 volts potential difference for each set of pencils.

While every precaution was taken to avoid discrepancies, it is clear that from the nature of the substance experimented upon, and the extreme difficulty of maintaining constant conditions, errors are apt to creep into the work. But the results given in table 3 as well as later determinations undoubtedly point to the existence of such a law as has been quoted.

The relation between diameter and life having been investigated, experiments were then made to determine the curve for current and mortality of the pencil, when the voltage is kept constant.

For this purpose a number of molded high tension carbons of the brand E were used. To secure uniformity in the plus and minus pencils, a 12 inch stick was broken in half, one portion being used as the upper, the other as the lower carbon. The length of each run was an hour. Current and potential were read every two minutes and the mean taken.

Table 4 gives the data from which the curve for current and mortality (Fig. 3) was plotted.

TABLE 4.

LIFE WITH DIFFERENT CURRENTS AND CONSTANT POTENTIAL.

Carbon.	Diam. mean inches.	Resis. ohms.	Initial wt. + grms.	Initial wt. − grms.	C. amp.	P. D. volts.	Loss wt. + grms.	Loss wt. − grms.	Life per inch. Carbon burned hours.	Life − / Life +
E molded high ten.	.518	.199	30.20	21.15	6.02	49.3	4.48	2.77	.6723	1.62
"	"	"	25.72	18.38	7.04	49.7	4.87	3.19	.6047	1.54
"	"	"	20.85	15.19	8.01	49.9	5.42	3.25	.5623	1.66
"	"	"	37.56	24.16	8.99	49.9	5.81	3.63	.5450	1.60
"	"	"	31.75	20.53	10.01	49.3	6.16	3.98	.5072	1 52
"	"	"	30.52	21.72	11.00	50.2	6.67	4.18	.4910	1.60
"	"	"	34.30	26.90	12 08	50.3	6.65	4 35	.4637	1.52
"	"	"	37.78	26.33	13.00	50.1	7.26	4.61	.4502	1.57

As will be seen the range of current was from 6 to 13 amperes. The greatest variation of the mean E. M. F. for the several runs was one volt.

TABLE 5.

LIFE WITH DIFFERENT POTENTIALS AND CONSTANT CURRENT.

CARBON.	Mean Diam; inches. +	Mean Diam; inches. −	Resis. ohms.	Initial wt. + grms.	Initial wt. − grms.	C. amperes.	P. D. volts.	Loss wt. + grms.	Loss wt. − grms.	Life per inch Carbon burned, hours.	Life − / Life +
E molded high ten.	.513	.513	.199	51.58	48.32	10	40	5.625	2.32	.6425	2.344
"	.521	.517	.197	37.65	24.16	10	45	5.605	2.87	.6077	1.953
"	.531	.522	.185	24.86	19.06	10	50	5.83	3.49	.5453	1.693
"	.531	.522	.185	24.86	19.06	10	55	6.34	4.025	.4903	1.589
"	.527	.530	.191	23.52	19.34	10	60	6.70	4.41	.4525	1.484

A series of tests was now made with constant current and varying voltage. The current in this case was maintained at ten amperes, and the range in tension was from forty to sixty volts. Carbons of the same type as in the last instance were used. In table 5, are given the figures for these runs and Fig. 14 shows the curve for voltage and mortality.

In the curves (Figs. 13 and 14), the ordinates represent the life of an inch of carbon in minutes. Reference is made not to the mortality of the plus pencil, but to the total amount of carbon burned in the lamp. The last two columns in Table 5, have been corrected for diameter and resistance of the pencil, the diameter and resistance respectively of the carbon that was burned at 10 amperes and 45 volts having been taken as a standard, and the life of the other pencils reduced to a common basis from this, according to the law previously stated.

Very little has been published regarding the relative life of the plus and minus carbons. Those books in which the subject is alluded to, state as a rule that with direct currents, the life of the upper carbon is about half that of the lower, provided both have the same length originally. In a recent publication [1] the general statement is made that "with continuous currents the plus wastes twice as fast as the minus carbon. With alternating currents the upper wastes 8 per cent. faster than the lower if the carbons are vertical; but at the same rate if horizontal."

TABLE 6.

RELATIVE LIFE OF THE PLUS AND MINUS CARBONS.

CARBON.	Initial wt. + grms.	Initial wt. − grms.	C. ampere.	P. D. volts.	Length run; minutes.	Loss wt. + grms.	Loss wt. − grms.	$\left\{\frac{\text{Life } 1'' -}{\text{Life } 1'' +}\right\}$
B molded high ten.	48.38	25.22	10	50	60	5.28	4.40	1.20
B molded low ten.	61.43	31.37	10	50	60	5.14	3.27	1.57
A molded high ten	90.57	38.68	10	50	60	5.98	3.20	1.87
10 E forced low ten	344.68	244.64	22½	28	150	193.18	74.42	2.59
10 B molded low ten.	367.80	259.50	22½	28	150	166.60	51.50	3 23
10 C molded low ten.	594 40	294.50	22½	28	145	151.00	41.00	3.68

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[1] Munro & Jamiesons' Electrical Rules and Tables, 1889.

No experiments were made upon arc-light carbons fed by alternating currents but an investigation of the relative loss of the plus and minus pencils with direct currents gave quite interesting results. Table 6 shows that the plus carbon may burn away about as fast as the minus, or may waste more than three and a half times as quickly.

Three sets of experiments were undertaken to determine the elements that affect this ratio.

FIRST. Effect of changing the diameter and resistance of the pencils with constant current and potential.

SECOND. Influence of change of current with constant potential.

THIRD. Change of potential with constant current.

For determining the influence of diameter and resistance upon the relative life of the plus and minus carbons, a number of molded high tension pencils of the brand A were used. The carbons were supposed to have been taken from the same "batch" and were burned with a current of 10 amperes and a P. D.=50 volts.

Examining table 7, which gives the results of measurements we note that $\left\{\frac{\text{life}-}{\text{life}+}\right\}$ appears to become greater with increase of diameter of the carbon. It is probable that the inequality in the diameters of the + and — pencils respectively, as well as the difference in the resistances of the two carbons of a set explains to a large extent the cause of this increase in the ratio. For assuming that under the conditions maintained, the life of a carbon varies directly with its diameter and inversely with its resistance, the data, (Table 7) indicate that if the diameters and resistances respectively of the + and — carbons were the same in each run, the ratio would be practically the same for all sizes of carbons. This is brought out in the last column of the table, which gives the corrected values of $\left\{\frac{\text{life}-}{\text{life}+}\right\}$

SECOND. Reference to the last column of Table 4 will show that a change in the current, other conditions remaining the same, probably has no effect on the ratio $\left\{\frac{\text{life}-}{\text{life}+}\right\}$. For when a current of 6 amperes was used, the ratio was equal to 1.62; at 7 amperes the ratio dropped to 1.54; it then alternately increased and decreased to 13 amperes. Hence it may be said that if all

TABLE 7.

INFLUENCE OF DIAMETER AND RESISTANCE OF THE CARBON UPON THE RELATIVE LIFE OF THE + AND — PENCILS.

CARBON.	Mean diam. inches. +	Mean diam. inches. −	Resis. Ohms. +	Resis. Ohms. −	Initial wt. +	Initial wt. −	Loss wt. +	Loss wt. −	$\left\{\frac{\text{Life } 1'' -}{\text{Life } 1'' +}\right\}$	$\frac{\text{Life } 1'' -}{\text{Life } 1'' +}$ corrected
A molded high ten.	.3964	.4083	.255	.240	37.91	16.97	4.96	3.04	1.63	1.79
"	.4567	.4567	.225	.243	48.98	20.26	5.41	3.2[illegible]	1.65	1.78
"	.5018	.5153	.199	.207	59.87	25.10	5.86	3.59	1.63	1.74
"	.5698	.5622	.178	.190	69.83	26.91	6.23	3.61	1.73	1.81
"	.6311	.6268	.152	.149	90.57	38.68	5.98	3.20	1.87	1.83

errors of observation, as well as those due to irregularities in the carbons could be eliminated, the $\frac{\text{life — carbon}}{\text{life + carbon}}$ would be found to be constant.

THIRD. The last column of Table 5 contains the data for $\frac{\text{life} -}{\text{life} +}$ with different P. D.'s and constant current. From these calculations it appears that the ratio depends on the P. D. and that the greater the P. D., the more nearly does the former approach unity. The curve plotted from the figures in table 5, is given in Fig. 15, the abscissæ being volts, and the ordinates representing the ratio of the life of the minus to the life of the plus carbon.

Thus the causes that influence the relative life of pencils of the same diameter, lie chiefly in the difference in the resistance of the carbons and the variations of P. D.

Judging from existing theories of the arc, it was thought that blowing the latter with a magnet during the runs would relatively increase the life of the plus carbon. The experiment was tried and the reverse was found to take place, *i. e.*, the ratio $\left\{\frac{\text{life} -}{\text{life} +}\right\}$ increased while the life of the minus pencil was not much affected.

EFFICIENCIES.

Two methods of determining the efficiency of each set of pencils were employed. The first was the method used by Mr. Merritt in obtaining the efficiency of the incandescent lamp[1] and subsequently by Mr. Nakano in his work on the efficiency of the arc-lamp[2]. The second dealt with candle-powers and will be referred to in the discussion of candle-power measurements.

It may not be amiss to give here an outline of the first method employed. A Thomson lamp was mounted on a movable frame and the rays from the burning carbons allowed to fall on the face of a thermo-pile, the latter being in circuit with a sensitive Thomson galvanometer. The deflection of the galvanometer was taken as a measure of the energy of the total radiation which fell upon the face of the pile. A cell containing a solution of alum was then interposed between the light and the pile, and the reduced deflection of the galvanometer noted. On the supposition that the alum cell cut off all the "dark heat" and allowed only the rays of the visible spectrum to reach the face of the thermo-pile, the last measurement would give the true value of the luminous energy emitted by the lamp. But a small percentage of the longer wave lengths passes through the alum cell, and a large part of the luminous rays is cut off by its intervention. Corrections having been made for these factors, the true values of luminous radiation resulted.

A mechanism was provided by which measurements could be made at various angles below the horizontal plane without altering the distance between the center of the arc and the thermo-pile.

For the high tension runs, the lamp was fed by a current of 9 amperes, the potential difference between its terminals being kept at 45 volts. For low tension tests, current = 21½ amperes, and P. D. = 30 volts. Note that the amount of energy expended in the low tension lamp was 21½ × 30 = 645 watts, while the high tension required but 9 × 45 = 405 watts. Although normally the former requires from 520 to 560 watts, unsteadiness of the light when the lamp was run below 21½ amperes made accurate measurements impossible.

Tables 8-15 give the results of efficiency tests. In the column

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[1] E. G. Merritt: Some Determinations of the Energy of the Light from Incandescent Lamps. Amer. Jour. Science. Vol. 37. p. 167.

[2] H. Nakano: Efficiency of the Arc Lamp; Transactions Amer. Inst. Elec. Eng. Vol. VI, p. 308.

EFFICENCY MEASUREMENTS.

TABLE 8.

Carbon A. Molded High Tension.

Angle.	L	T	$\frac{L}{T}$
0°	6.085	110	.0553
10°	8.112	130	.0624
20°	11.49	134	.0858
30°	16.90	146	.1158
40°	23.67	146	.1621
50°	15.55	143	.1087
60°	10.14	125	.0811

TABLE 9.

Carbon D. Forced High Tension.

Angle.	L	T	$\frac{L}{T}$
0°	4.733	107	.0442
10°	8.133	118	.0688
20°	11.49	129	.0891
30°	14.20	142	.0977
40°	16.91	152	.1112
50°	19.61	156	.1257
60°	8.790	142	.0619

TABLE 10.

Carbon B. UNPLATED Molded High Ten.

Angle.	L	T	$\frac{L}{T}$
0°	10.14	114	.0889
10°	13.52	127	.1065
20°	15.55	144	.1080
30°	18.26	157	.1163
40°	22.31	165	.1352
50°	22.31	163	.1369
60°	15.55	156	.0995

TABLE 11.

Carbon B. PLATED Molded High Ten.

Angle.	L	T	$\frac{L}{T}$
0°	11.49	116	.0991
10°	14.21	128	.1057
20°	15.55	145	.1072
30°	19.60	157	.1248
40°	22.31	164	.1361
50°	18.93	164	.1369
60°	15.55	141	.1103

TABLE 12.

Carbon E. Molded High Tension.

Angle.	L	T	$\frac{L}{T}$
0°	2.702	116	.0233
10°	5.405	134	.0403
20°	8.108	146	.0555
30°	13.51	157	.0861
40°	17.57	159	.1105
50°	11.48	145	.0792
60°	7.77	112	.0710

TABLE 13.

Carbon E. Forced High Tension.

Angle.	L	T	$\frac{L}{T}$
0°	2.702	118.5	.0228
10°	4.054	131.0	.0310
20°	6.756	158.	.0428
30°	6.081	——	.0483
40°	10.13	175.0	.0579
50°	14.19	155.0	.0895
60°	11.48	136.0	.0844

TABLE 14.

Carbon A. Forced Low Tension.

Angle.	L	T	$\frac{L}{T}$
0°	8.784	162	.0542
10°	12.16	170	.0715
20°	20.27	185	.1095
30°	25.68	190	.1351
40°	25.68	190	.1351
50°	16.89	157	.1080
60°	9.459	130	.0728

TABLE 15.

Carbon B. Molded Low Tension.

Angle.	L	T	$\frac{L}{T}$
0°	10.81	190	.0569
10°	17.57	211	.0833
20°	25.68	223	.1151
30°	28.38	223	.1273
40°	17.57	215	.0817
50°	12.33	182	.0678
60°	6.081	135	.0451

headed (L) are given the corrected values of deflections due to luminous radiation; the values of (T) refer to total radiation and the efficiency or luminous divided by total radiation $= \left\{\frac{\mathrm{L}}{\mathrm{T}}\right\}$.

These tables furnish the date from which the curves (Figs. 16-23 were plotted. The radii show the positions for which measurements were taken and distances measured along these lines from the origin to the *dotted* curves, give the intensity of luminous and total radiation respectively in each position.

It will be seen that the distribution of total radiation differs considerably from that of luminous radiation hence the efficiency, which is expressed by $\left\{\frac{\text{luminous radiation}}{\text{total radiation}}\right\}$ depends upon the angle of measurement.

The full-line curves (Figs. 16-23) represent the efficiencies of the various carbons. In order to obtain the mean or hemispherical efficiency, the areas of the curves of luminous and of total radiation were found by means of the planimeter; now the ratio of the radii of two semi-circles whose areas are respectively equal to those of the curves of luminous and total radiation, is the value of the mean spherical efficiency. This value has been calculated for each set of pencils and the results are given in Table 16; also in Figs. 16-23.

TABLE 16.
EFFICIENCY MEASUREMENTS.

CARBON.	Diam. mean inches.	Resis. ohms.	C. amp.	P. D. volts.	Horizontal efficiency.	Maximum efficiency.	Hemi-spherical efficiency.	Life 12 inch + carbon hours.	C. / P. D.
A molded high ten.	.506	.203	9	45	.0553	.1621	.1171	10.22	(10 -50)
D forced high ten.	.457	.187	9	45	.0442	.1257	.1001	8.64	(10 -50)
B molded (unplated) high ten.	.458	.224	9	45	.0889	.1352	.1269	9.16	(10 -50)
B molded (plated) high ten.	.458	.0805	9	45	.0991	.1369	.1272	10.64	(10 -50)
E molded high ten.	.588	.202	9	45	.0233	.1105	.0896	10.29	(10 -50)
E forced high ten	.522	.251	9	45	.0228	.0895	.0776	10.09	(10 -50)
A forced low ten.	500	.072	21.5	30	.0542	.1351	.1105	10.55	(21½-30)
B molded lowten.	.498	.071	21.5	30	.0569	.1278	.0932	9.42	(22½-28)

We notice that the horizontal efficiency is very small compared with the maximum; that relatively high efficiency in a *forced high tension* carbon is obtained only at the expense of life; that a *molded* carbon is, generally speaking, superior to a *forced* for high tension and vice versa for low tension.

In the case of the high tension carbons B and D, the diameters are smaller than those of the other pencils, hence we are to expect a relatively higher efficiency since as was shown last year, the "efficiency varies inversely as the diameter."[1]

A point of interest brought out by these tests (Tables 10 and 11 and Figs. 18 and 19), is the fact that while the life of a copper plated carbon is greater than that of an unplated carbon of the same diameter and type, the mean spherical efficiency appears to be the same for both.

Two sets of pencils of the brand (B), the one unplated and the other plated, were burned to ascertain this relation. The results show that the horizontal and the maximum efficiency of the copper-plated carbons were a little greater than those of the uncoated pencils respectively, and the mean spherical efficiency in the latter case was very slightly less than in the former. As can be seen from Table 16, the life of the "positive" plated pencil (12″ long) was 10.64 hours, while that of the naked carbon was 9.16 hours, the current and P. D. having been the same for both cases.

No positive explanation of this phenomenon has yet been given but it appears that the actual amount of *combustion* in both cases is the same while the *disintegration* caused by the passage of the current is greater in the case of the unplated carbon.

CANDLE POWER MEASUREMENTS.

The candle-power measurements consisted chiefly in the determination of the hemi-spherical candle-power of the different pencils and from this quantity, the watts per spherical candle-power produced.

The runs were made under the same conditions as in the efficiency tests. For high tension carbons current — 9 amperes and P. D. — 45 volts. For low tension pencils, current — 21.5 amperes and P. D. — 30 volts.

To ascertain the candle-powers, the method of the Franklin

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[1] H. Nakano.

Institute Committee was used.[1] The photometric apparatus was somewhat different in detail from that ordinarily used in measuring the candle-power of incandescent lamps and deserves a brief description.

The arc-lamp was suspended from an arm which could be rotated about an axis parallel to the photometer bar and vertically above it. By manipulating a rope connected with the arm, the latter could be raised until it was at right angles with the photometer-bar, or lowered until it was horizontal. The arm being horizontal, the lamp was hung from its extremity so that the arc was on a level with the center of the photometer-disc. It will be seen that when the arm was pulled up, the arc described a vertical circle, the axis of which was a line parallel to the photometer-bar and passing through the center of the disc. The centre of the vertical circle was at the point (800) of a scale graduated into (1,000) divisions, and the radius equal to the length of (200) scale divisions.

At the zero of the scale was placed a Weston incandescent lamp, and a circular mirror of silvered glass, the axis of which was horizontal and inclined 45° to the reflecting surface, was mounted on the bar so that its centre coincided exactly with the 800th division of the scale. Thus the distance between the arc-lamp and the mirror was rendered constant for all elevations of the former, and when the mirror reflected the light of the lamp upon the disc, the angles of incidence and reflection were always equal to 45°. The virtual image of the arc under these circumstances was at the 1000th division of the scale. The Weston lamp was used as a secondary standard and maintained by a storage battery throughout the runs at 115 volts; its candle-power was ascertained before and after the tests by comparing it with a standard Methven "Board of Trade" 2 c. p. slit.

Photometer readings were made as in the case of the efficiency tests, at 0° and at 10°, 20°, 30°, 40°, 50°, and 60°, below the horizontal, the mean of twenty observations being taken for each elevation. These measurements were multiplied by the candle-power of the secondary standard and corrected for absorption of light by the mirror.

Tables 17-23 gives the corrected data, which form the basis of the candle-power, curves (Figs. 24 and 25). Distances measured along the radii from the origin to each curve, give the candle-power for the various angles. The mean spherical candle power for any case is measured by the radius of a semi-circle whose arc is equal to the area of the c. p. curve.

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[1] Reports; International Electrical Exhibition of Franklin Inst. 1884. Group B, Sections V and VIII.

CANDLE POWER MEASUREMENTS.

TABLE 17.

Carbon A; molded high tension.

Angle.	Candle-power.
0°	221.3
10°	474.1
20°	713.1
30°	979.2
40°	1053.0
50°	928.6
60°	370.7

TABLE 18.

Carbon B; molded high tension.

Angle.	Candle-power.
0°	382.2
10°	638.4
20°	908.4
30°	1113.
40°	1131.
50°	749.3
60°	579.8

TABLE 19.

Carbon D: forced high tension.

Angle.	Candle-power.
0°	210.5
10°	407.4
20°	687.4
30°	977.1
40°	1079.0
50°	1140.
60°	595.7

TABLE 20.

Carbon E; molded high tension.

Angle.	Candle-power.
0°	227.3
10°	288.8
20°	429.9
30°	722.2
40°	957.2
50°	1080.0
60°	414.0

TABLE 21.

Carbon E; forced high tension.

Angle.	Candle-power.
0°	221.7
10°	238.
20°	350.1
30°	558.9
40°	626.8
50°	630.7
60°	235.5

TABLE 22.

Carbon A; forced low tension.

Angle.	Candle-power.
0°	593.7
10°	712.1
20°	86 .3
30°	1094.
40°	1183.
50°	683.2
60°	495.4

TABLE 23.

Carbon B; molded low tension.

Angle.	Candle-power.
0°	475.4
10°	593.7
20°	720.9
30°	871.3
40°	866.6
50°	528.4
60°	354.8

Although great care was taken in ascertaining the candle-powers, the difference in color between the light emitted by the arc and that given by the standard was so marked that the setting of the photometer-carriage was to a large extent a matter of personal judgment; hence the measurements given cannot be considered as absolute, but rather as relative values.

The conclusions drawn from the efficiency curves hold generally, as will be seen by an examination of Table 24, for the candle power curves. From the latter it appears that the efficiency of low tension carbons, and especially of *molded* low tension pencils is comparatively small While the efficiencies of molded high tension carbons are as high as .953 and .888 watts per spherical candle or 783 and 840 candles per electrical horse-power expended in the lamp, the efficiencies of low tension pencils of nearly the same diameter as the high are as small as 1.255 and 1.612 watts per candle or 594 and 502 candles per electrical horse-power.

This fact is not brought out in Table 16, for reference to the latter shows the low tension pencils to have a rather high efficiency, and in some cases considerably higher than the high tension carbons. However, when the energy expended in the lamp in the two cases respectively is taken into account, the explanation of the high values for carbons A and B (Table 16, low tension) is apparent.

TABLE 24.

CANDLE POWER MEASUREMENTS.

CARBONS.	Diam. (mean) inches.	Resis. ohms.	C. amp.	P. D. volts.	Horizontal Candle-power.	Maximum c. p.	Hemi-spherical c. p.	Watts per spher. p. c.	Spher. c. p. per Elec. horse-power
A molded high ten.	.508	.203	9	45	221	1058	456	.888	840
D forced high ten.	.457	.187	9	45	210	1140	486	.833	895
B unplated molded high ten.	.453	.224	9	45	382	1131	525	.771	967
E molded high ten.	.533	.202	9	45	227	1080	425	.953	783
E forced high ten.	.522	.251	9	45	222	626	288	1.407	531
A forced low ten.	.500	.072	21.5	30	594	1183	514	1.255	594
B molded low ten.	.498	.071	21.5	30	475	871	400	1.612	502

Carbon B (molded high ten., Table 24), it will be noted has the highest efficiency of the group. This is due largely to the fact that its diameter is smaller than that of any of the others, for "the candle-power varies inversely as the diameter."[1]

Similarly the relatively high candle-power of carbon D is accounted for by the small diameter of the pencil. In Table 24 and the candle-power curves, we again note the comparatively small efficiency of *forced* high tension carbons.

The efficiency of carbon A., (molded high tension, Table 16), as measured by $\left\{\frac{\text{luminous radiadion}}{\text{total radiation}}\right\}$ is larger than that of carbon D; yet the mean spherical candle power of the latter is greater than that of the former (Table 24). The explanation of this phenomenon (assuming the measurements to be correct) probably lies in the difference in the *quality* of the light emitted.[2]

In some instances it is desirable to ascertain the mean spherical candle-power of a lamp approximately, without taking the time to integrate the curve.

The formula given by M. Gerard, namely, "spherical c. p. = $\frac{1}{2}$ horizontal c. p. + $\frac{1}{4}$ maximum c. p."[3] is of sufficient exactitude for practical purposes. Gerard gives the following table showing the observed and calculated spherical candle-powers for seven lamps.

TABLE 25.

GERARD'S MEASUREMENTS OF CANDLE POWER.

LAMPS.	Horizontal c. p.	Maximum c. p.	Spherical c. p. calculated.	Spherical c. p. observed.
No. 1	250	1464	491	470
" 2	456	3250	1040	1145
" 3	560	3071	1048	1221
" 4	744	1227	679	692
" 5	122	840	271	274
" 6	586	2100	818	802
" 7	935	1150	755	767

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[1] M. Schreihage: Centralblatt für Elektrotechnik, No. 22, 1888.

[2] The reader is referred in this connection to, "A Spectrophotometric Comparison of Artificial Sources of Illumination." Paper by Edward L. Nichols and W. S. Franklin, read before A. A. A. S. at Cleveland, August, 1888.

[3] M Gérard: Candle Power of Arc Lamps:—Centralblatt für Elektrotechnik, also N. Y. Elec. World, Jan. 25th, 1890.

Taking the whole number of lamps, the average error is only five per cent. "The angle of maximum intensity was about 45° usually, but in some cases it approached that of 30° or 60° from the horizontal."

Data collected from various sources, including the tests of the Franklin Institute Committee in 1884, are given in Table 26. From the horizontal and maximum candle-powers, the mean spherical was calculated by Gerard's law. Comparison with the observed candle-powers shows that in some cases the error is less than one per cent. The mean error is, however, larger than that obtained by Gerard, and reaches about 9¾ per cent. Hence as was stated before, the law is valueless except in cases of rough approximation.

TABLE 26.

CANDLE-POWER CALCULATIONS, USING GÉRARDS' LAW.

LAMPS.	Horizon. c. p.	Max. c. p.	Spherical c. p. observed.	Spherical c. p. Calculated.	Authority.
Weston	344	609	348	324	B. W. Snow.
"	299	576	295	293	"
"	576	1235	640	597	"
Brush	813	1395	609	504	"
Ball	283	534	240	249	Prof. W. A. Anthony
Brush (1200 c. p.)	180	617	263	244	"
Brush (2000 c. p.)	389	1380	653	539	"
Van Depoele (20 light)	451	1377	574	569	"
Van Depoele (60 light)	333	1155	470	455	"
Western Elec.	263	355	186	220	"
Thomson-Houston.	227	1080	425	383	L. B. Marks.
" "	222	626	288	267	"
" "	382	1181	525	474	"
Weston	594	1188	514	593	"
"	475	871	400	436	"

Reference has been made to the fact that while the curve for luminous radiation is similar to that of candle-power, the curve for total radiation differs widely from the latter. As the efficiency depends upon the ratio $\left\{\frac{\text{luminous radiation}}{\text{total radiation}}\right\}$ it is plain that Gerard's law will not hold for calculating the mean spherical efficiency from the horizontal and the maximum. But again, for approximations a similar law holds, *i. e.*,

Spherical efficiency—¼ *horizontal*+¾ *maximum.*

Although the topic of efficiencies has been discussed in another part of the article, it may not be out of place to add a few words here, bearing upon the law in question. Measurements of horizontal, maximum and mean spherical efficiency, made by Mr. H. Nakano and by the writer, are given in Table 27, and the last law mentioned applied in the calculation of the spherical efficiency. In some cases the error is exceedingly small while in others it is comparatively large; the mean error of fourteen tests is not quite 8 per cent.

TABLE 27.

OBSERVED AND CALCULATED EFFICIENCIES.

CARBON.	Horizon Effic.	Max. Effic.	Spherical Effic. observed.	Spherical Effic. calculated.
.832 inch.	1.82%	9.00%	6.87%	5.60%
.563 "	4.12%	14.41%	11.00%	11.83%
.500 "	4.91%	17.33%	12.66%	14.22%
.450 "	5.48%	15.52%	13.30%	13.01%
.370 "	5.55%	17.50%	15.54%	14.51%
.250 "	8.44%	19.80%	16.60%	16.96%
A molded high ten.	5.53%	16.21%	11.71%	13.53%
D forced "	4.42%	12.57%	10.01%	10.53%
B (unplated) "	8.89%	13.52%	12.69%	12.37%
B (plated) "	9.91%	13.69%	12.72%	12.75%
E molded "	2.33%	11.05%	8.96%	8.87%
E forced "	2.28%	8.95%	7.76%	7.29%
A forced low ten.	5.42%	13.51%	11.05%	12.68%
B molded "	5.69%	12.78%	9.82%	10.96%

OBSERVATIONS OF THE ARC AND THE CARBON-POINTS.

With a given potential difference between the terminals of the lamp, the length of the arc depends upon the current flowing, and increased as the current becomes greater. If the current be kept constant, the length of the arc increases with the P. D.

Data given in Tables 28 and 29 show the length of the arc for both cases.

TABLE 28.

LENGTH OF ARC: CONSTANT POTENTIAL.

CARBON.	Current amp.	P. D. volts.	Length of arc; inches.
E, molded high tension.	6	50	.087
" "	7	"	.114
" "	8	"	.137
" "	9	"	.147
" "	10	"	.150
" "	11	"	.154
" "	12	"	.156
" "	13	"	.167

TABLE 29.

LENGTH OF ARC: CONSTANT CURRENT.

CARBON.	Current amp.	P. D. volts.	Length of arc; inches.
E, molded high tension.	10	40	.073
" "	"	45	.095
" "	"	50	.141
" "	"	55	.186
" "	"	60	.216

In order to measure the length of the arc, a lens was so mounted as to throw the magnified image of the former upon a surface carrying a vertical scale. Then after measuring the distance between the magnified points and applying the proper reduction factor, an additive correction was made for the depth of the crater, thus giving the length of arc from the tip of the minus pencil to the point directly above in the center of the crater of the plus.

From the figures (Tables 28 and 29), it seems that no direct relation exists between the length of the arc and the current and P. D. In the case of the carbons tested, the length of the arc with constant potential increased very rapidly as the current was changed from 6 to 9 amperes, and then gained slowly from 9 to 13 amperes. The nature of the change was somewhat different in the constant current runs, the length of the arc increasing more nearly as the square of the voltage.

After each of the runs noted in Tables 28 and 29, the carbon-points were examined, and it was found that the latter assumed particular shapes depending upon the current and P. D. used. Another series of tests were made with carbons C. and E. (molded high ten), in which the current ranged from 5 to 15 amperes, the P. D. being kept constant at 50 volts.

Fig. 26 shows the form of the points with different currents. Nos. 1, 2 and 3 are pencils of the brand C and 4, 5, 6 and 7 of the type E. The photographs of the carbons, Fig. 27, are three-quarters of the actual size.

Examining the first three pencils, we see that with 5 amperes, there is a tendency to form a "mushroom" on the lower or negative carbon; the latter is eaten away considerably just below the tip. With 10 amperes this tendency is not at all marked and at 15, almost inappreciable.

Glancing at the upper or plus carbons, it appears that the smaller the current, the more nearly does the positive pencil burn to a point, that is, the smaller the diameter of the crater. But though the width of the crater is less in the case of low currents than with high, the depth of the former is correspondingly greater. The photographs do not bring out this point, but an inspection of the tip of the lower carbon gives a clue to the facts. Note that with small currents the negative electrode terminates in a pointed, sometimes globular projection. As has been stated before this, tip becomes less noticeable with increase of current, a fact which is brought out by inspecting Nos. 7. 6, 5 and 4 (Fig. 26.) In No. 4, burned at 15 amperes, the end of the lower carbon is blunted; the depth of the crater in the upper was practically zero. In Nos. 5, 6 and 7 burned at 12, 9 and 6 amperes respectively, the depth of the crater increases as the current diminishes.

With high currents, the carbon is disintegrated to a greater distance above the point than with low.

Fig. 27 shows the form of the carbon points when the latter are burned with constant current=10 amperes. The range in P. D. was from 40 to 60 volts.

Just as the peculiar burning of the tip distinguishes a pencil fed by a low from one burned at a high current, so the form of the carbon-point differs in the case of a pencil burned with low voltage than with high. In Nos. 1, 2, 3, 4 and 5, Fig. 27, the gradual change in the formation, from a sharp projection at 40 volts to a blunt end at 60 volts is noticeable.

The "mushroom" which invariably forms in carbons burned at a low current and high voltage, is absent when the pencils are burned at high current and low voltage[1] In the former instance the thin neck of the "mushroom" often breaks thus arresting the current and extinguishing the arc. In the latter case the end of the carbon is prone to so burn away as to leave a concave outline. (See No. 1, Fig. 27.)

At 40 volts the depth of the crater measured .051 inch. At 60 volts the crater disappeared; the carbons also "flamed" at this high voltage.

With a given current there is for every brand of carbon a certain voltage, above which, if the pencil be burned, "flaming" will result. A simple trial is sufficient to determine this critical point.[2] Again there is a voltage, below which, if the carbon be burned, "hissing" takes place. With perfectly centered carbons there is no difficulty in ascertaining the latter point.

Careful observation of the arc shows that when the tension is too high for a given carbon, the walls of the crater break away, allowing the arc to play on the outside surface of the carbon. This action is always accompanied by a flame, which shoots from the negative carbon. On placing the negative pencil above and the positive below, the flame shoots down. With soft-cored carbons, well centered, one cause of flaming,—namely, liability of the arc to play laterally,—is obviated; and if the pencils be burned with the proper current and voltage, there seems to be no reason why this disagreeable feature of the arc lamp, should not be entirely overcome.

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[1] When the carbon is impure and contains a large amount of silica, the latter is often deposited in the form of a glass bead on the point of the negative pencil. The "mushroom" alluded to in the text does not refer to this deposition.

[2] O. G. Pritchard: Electric Arc Light Carbons. London Elec. Mar. 21st and Apr. 4th, 1890.

There is not so much liability to "hiss" in a high tension system as in a low, for from the formation of the carbon-points when the pencils are burned in commercial low tension lamps, it appears that the minus carbon terminates in a small mushroom-button. The breaking of this pellicle of carbon and the consequent action of the lamp-mechanism to reduce the rise in potential due to the rupture, invariably result in the "hissing" of the arc.

Most of the irregularities in the action of arc-lamps probably result more from the unsuitableness of the carbon than from defects in the lamp-mechanism or changes in the strength of the current and P. D. in the line.

The remedy lies with the carbon-manufacturer. A careful study of the relation between the microscopical structure of the pencil and the action of the latter in a given case would be likely to bear fruitful results. Of course the field for experimentation is large, but the improvements which must necessarily follow conscientious research will undoubtedly be of great scientific as well as commercial value.

In the present state of the art of carbon-manufacture, it is the central-station manager who must exercise great discrimination in the selection of arc-light pencils for his plant. Mr. E. F. Peck has recently shown how a "comparative test of the best known carbons in the market" resulted in "a saving of 64.73 electrical horse-power in a station burning a thousand arc-lamps."[1]

But there is no reason why the carbon-manufacturer, given the condition of a lighting system as regards current, tension, required light and life of pencils, etc.—should not be able to produce a carbon specially adapted to the needs of that system.

When the root of existing defects is thus struck at, the solution of the arc-light carbon problem will be at hand.

The experiments published in this paper were made under the direction of Professor Edward L. Nichols, in the laboratory of Cornell University. The writer is indebted to Mr. A. B. Levy, R. G., for valuable assistance in the work.

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[1] E. F. Peck of Brooklyn, N.Y.; Carbon Tests,—paper read before National Elec. Light Assoc'n; Kansas City Convention, Feb. 1890.

Physical Labratory of Cornell University.
Ithaca, N. Y., May 1890.

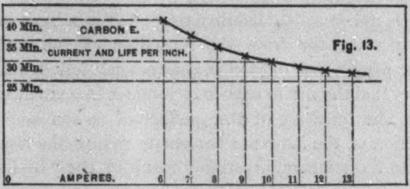


Fig. 13.

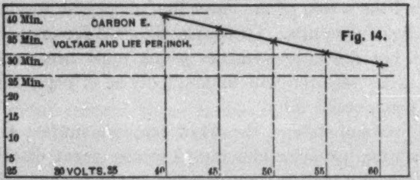


Fig. 14.

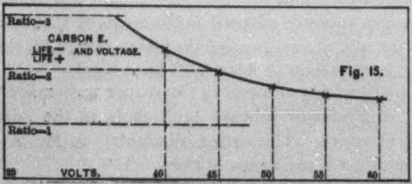


Fig. 15.

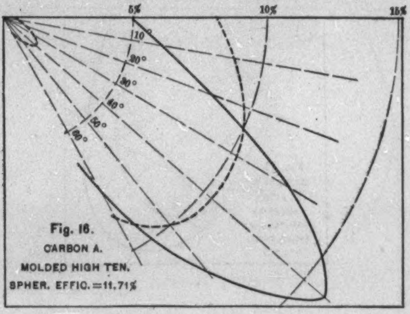


Fig. 16.
CARBON A.
MOLDED HIGH TEN.
SPHER. EFFIC.=11.71%

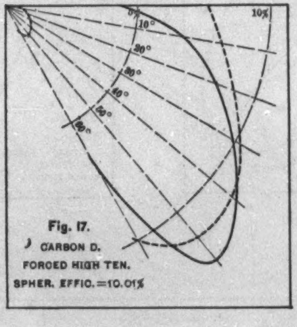


Fig. 17.
CARBON D.
FORCED HIGH TEN.
SPHER. EFFIC.=10.01%

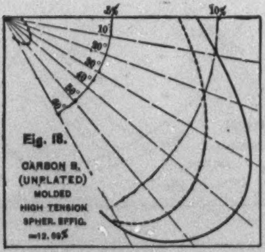


Fig. 18.
CARBON B.
(UNPLATED)
MOLDED
HIGH TENSION
SPHER. EFFIC.
=12.66%

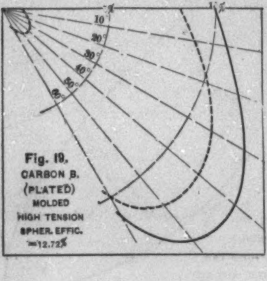


Fig. 19.
CARBON B.
(PLATED)
MOLDED
HIGH TENSION
SPHER. EFFIC.
=12.72%

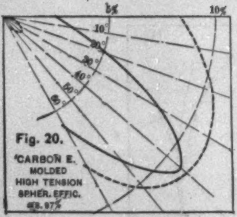


Fig. 20.
CARBON E.
MOLDED
HIGH TENSION
SPHER. EFFIC.
=8.97%

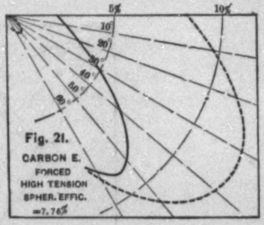


Fig. 21.
CARBON E.
FORCED
HIGH TENSION
SPHER. EFFIC.
=7.76%

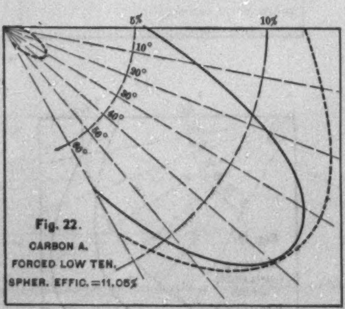


Fig. 22.
CARBON A.
FORCED LOW TEN.
SPHER. EFFIC. =11.05%

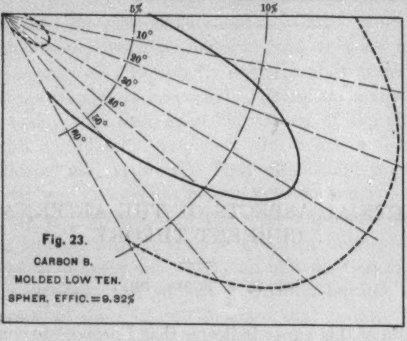


Fig. 23.
CARBON B.
MOLDED LOW TEN.
SPHER. EFFIC.=9.32%

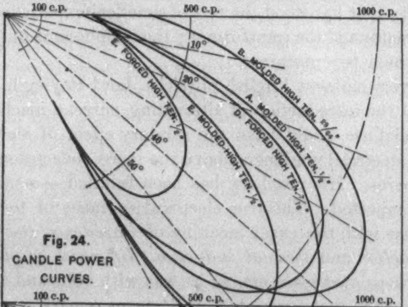


Fig. 24.
CANDLE POWER
CURVES.

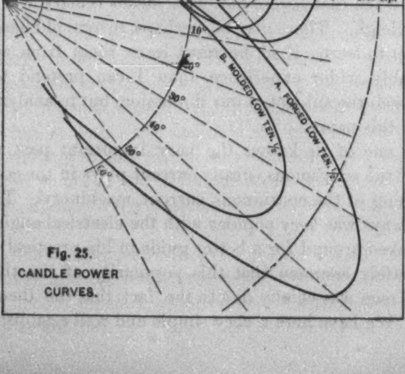


Fig. 25.
CANDLE POWER
CURVES.

A paper read before the American Institute of Electrical Engineers, Boston, May 21, 1890.

PRACTICAL ASPECTS OF THE ALTERNATING CURRENT THEORY.

BY M. I. PUPIN, PH. D.

The title of this paper indicates that I propose to consider that part of the alternating current theory only which refers to machinery that has stood the test of practical experience, namely, the alternator and the transformer; the telephone is only a special case of these two machines.

That very eminent English physicist, Lord Rayleigh, remarked once that the introduction of alternating current machinery into commercial use would have the salutory effect of elevating the ideas of electrical engineers above the mere conceptions of volts and amperes. His prophecy has been fulfilled—sooner perhaps than he expected. The true electrical engineer of to-day is just as familiar with the exact meaning of *impedence*, *co-efficients* of *self-induction* and *mutual induction*, *difference of phase*, *static* and *viscuous hysteresis*, etc., as he was with volts and amperes at the time when that severe but well meant remark was made by Lord Rayleigh. There may be, perhaps, several old lessons which he has yet to learn; if so, he must learn them from teachers of considerably wider experience than I can pretend to possess. Not to teach the subject of our discussion, but to analyze it, is the object of this paper.

Every one of us knows the very important part which the theory of the continuous, steady current plays in the construction and running of the continuous current machinery. This theory is and always was very popular with the electrical engineer. He never looked around for a better guide in his practical work. It can be safely assumed that this popularity of the theory with practical men was chiefly due to the fact that the theory is very simple. We have here a very simple and well established fundamental law, the Ohm's law namely, and most of the other relations of which this theory treats are deduced from this law by simple algebraical operations. Simplicity is the soul of truth, complicated relations are always suspected. There are many practical engineers to-day who look upon the theory of the alternating current with considerable suspicion. It seems to them to be too complicated and artificial. They also complain of a lack of sufficiently well defined distinctions between fundamental laws and arbitrary assumptions. In fact, this is the face which the alternating current theory, such as given in most of our text books, presents to every one who is not in a position to consider the subject critically and go just a little bit beyond the badly selected limits of some of our standard text books. There is, therefore, a strong disposition on the part of some engineers to doubt the importance which others attach to the alternating current theory. If the following discussion should succeed in contributing even a small share towards the work which must be done in order to dispel these doubts, I shall be satisfied.

The features of the alternating current theory which I propose to point out with particular emphasis are the following:

First: This theory, just like the theory of the steady current, rests on a very simple and well established fundamental law of which Ohm's law is only a particular case.

Secondly: All the simple relations of which the theory treats are deducible from this fundamental relation by easy mathematical operations.

Thirdly: Problems arising in the practical running of alternating current machinery are readily solved by considering the modifications which the exact but ideal relations of the theory must undergo under conditions which we meet in practice.

Let us consider a magnetic field made up of permanent magnets, electro magnets, closed circuits with steady or variable currents flowing in them; the magnets and the conductors may be at rest or moving in any continuous manner whatever. Let us next fix two points A and B on one of the conductors.

Let now E_s denote the electro-motive force in AB due to self-induction.

Let E_m denote the electro-motive force in AB due to induction between AB, and the rest of the field.

Let E_i denote an electro-motive force impressed upon AB in some way or another.

Let D denote the drop of the potential between A and B; then at any moment we have $(E_s)+(E_m)+(D)=(E_i)$.

This is the fundamental law of the alternating current theory. It is easily seen that Ohm's law is only a particular case of this fundamental relation. I have enclosed the symbols in parenthesis to denote that the absolute sign of each quantity is for the present left undetermined.

Just as the laws which govern the motions of the celestial bodies are all deducible from the single Newtonian law of gravitation, so all the laws governing the generation and the distribution of alternating current energy are deducible from that same fundamental law. The historian tell us that it took Newton twenty years to deduce his law of gravitation. It took more than one Newton to establish our fundamental law, and their labors extended over a period of more than thirty years. These Newtons of electricity were Ampère, Faraday, Lenz, Joseph Henry, F. Neumann, Helmholtz, Thomson and Maxwell.

A short critical review of the labors which led to the final formulation of the above fundamental law will not be out of place here.

Oersted's discovery was made in 1820; Ampère's and Arago's investigations of the magnetic properties of a steady electric current were brought to a close in 1823. The results of these investigations were embodied in the great work of Ampère: *Theorie des Phemomenes Electro-dynamique.* About this work immortal Maxwell speaks as follows: "The whole, theory and experiment, seems as if it had leaped full grown and full armed from the brain of the Newton of electricity. It is perfect in form, and unassailable in accuracy, and it is summed up in a formula from which all the phenomena may be deduced and which must always remain the fundamental formula of electrodynamics." The fundamental formula to which Maxwell refers is the well known differential law of Ampère. This statement Maxwell made before 1873; in 1874 Professor Helmholtz showed that it must be somewhat modified; for he pointed out for the first time that several other fundamental laws lead to the same integral law as the fundamental formula of Ampère. The integral law is the well known law which expresses the equivalence between a simple magnetic shell and a certain steady electric current. This integral law has been verified by all experimental experience of the last seventy years. It forms the basis of the electro-magnetic units which we use in our electrical measurements.

The next advance was made by Faraday in 1831, eight years after the publication of Ampère's discoveries, and a gigantic advance indeed it was. If we consider Faraday's discoveries in electro-magnetic induction from the stand-point only that they supplied the electrical science of his day with additional experimental facts they would fall very short indeed of the importance which is to-day, and that too very justly, as we all know, attributed to them. It is the experimental method and the scientific reasoning by means of which Faraday arrived at his brilliant discoveries, and the view which he formed of the new phenomena that raises his work to that supreme importance to which among all the physical investigations of this century one only can aspire. I refer, of course, to those investigations which led to the final formulation of the *Principle of Conservation of Energy.*

Faraday's discoveries found immediate appreciation in the scientific world. The view, however, which he had formed about the phenomena discovered by himself, made but a feeble impression upon his contemporaries. It was too novel, and the minds of the physicists of his time were strongly polarized by the irresistible mental force of Ampère, Poisson, Green, Gauss and Weber. At that time Thomson had only just mastered his a b c, and Maxwell was born in the same year in which Faraday published his first investigations on electro-magnetic induction.

The first attempt to formulate the laws which underlie all phenomena of electro-magnetic induction is contained in Lenz's discovery of the well-known rule that the direction of the currents induced in a conductor which moves in a magnetic field is always such as to oppose the motion which produces them. This discovery was made in 1834, the same year in which Faraday discovered the phenomena of self-induction. Joseph Henry's investigations on induction in general and self-induction in particular covered the period between 1832 and 1840. It is needless to say that these investigations form a necessary and a beautiful supplement to the investigations of Faraday. The resolution passed a short time ago by the American Metrological Society, to the effect to name the *unit of self-induction* after Joseph Henry is very appropriate and deserves the heartiest support of all electrical engineers. The final mathematical formulation of the law of what is to-day called *mutual induction* is due to F. Neumann, and is contained in his memoirs submitted to the Berlin Academy in 1845 and 1847. It was soon recognized that, since self-induction is only a special case of mutual induction, that the mathematical form of the fundamental law of self-induction must necessarily be a modification only of that of mutual induction. Maxwell, therefore, says this of Neumann: "We may regard F. Neumann, therefore, as having completed for the induction of currents the mathematical treatment which Ampère had employed for their mechanical action."

This statement of Maxwell contains more than one is apt to get from it at a glance. In Neumann just as in Ampère the mathematician predominates. They both belong to that school of mathematical physicists whose representatives are LaPlace, Poisson, Green and Gauss. Just as these great analysts had deduced most of the laws of electrostatics from the properties of a single function, the potential function, so Neumann succeeds in deducing the fundamental laws of electro-magnetic induction from the properties of a single function, the *electro-dynamic potential.* But neither were they nor was he at that time aware of that perfectly definite physical meaning which these functions enjoy to-day. This was pointed out for the first time by Helmholtz, and later on also by Sir William Thomson, the discoverers of the *Principle of Conservation of Energy* (in 1847), the fundamental principle and the infallible test-stone for all the laws of physical sciences. It is to these two men that we owe the introduction into theoretical physics of that most intelligible of all physical quantities, namely, *energy and work*, in place of mathematical symbols. With them, electrostatic potential of Poisson, Green, and Gauss, and the electro-dynamic potential of Neumann meant work; induced or any other kind of current was simply an evidence that some sort of work is being done upon the conductor. Their investigations extending from 1847 to 1853 showed clearly that the laws of electro-dynamic induction as formulated by Neumann on the basis of Lenz's discoveries was not only in full harmony with the Principle of Conservation of Energy, but that moreover this principle enables us to deduce these laws directly from the discoveries of Oersted and Ampère. This would seem to indicate that Faraday's discoveries were simply a welcome experimental confirmation of the laws which could have been deduced independently of these discoveries, and that they were therefore not essential to further progress of the electrical science at the time of Ampére. Maxwell, however, pointed out the real importance of Faraday's work. In 1856, only two years after he had graduated from the University of Cambridge, with the highest mathematical honors, appears his first research on Faraday's lines of force, and in 1865 already appears his great memoir, entitled: "The Dynamical Theory of the Electro-Magnetic Field." In these researches, and especially in his great treatise on Electricity and Magnetism, Faraday's discoveries, especially those on Electro-Magnetic Induction, appear to the scientific world in an entirely new light. It is on the basis of these discoveries and the view which Faraday had formed of them that Maxwell formulates the most general statement of the laws of induction. It is in the form in which the laws of electro-magnetic induction were first stated by Maxwell that they are generally known to the electrical engineers. This form not only expresses the law but also suggests the view which Farady had formed about electro-magnetic induction, which view, as we all know, has led to some of the greatest discoveries in electricity during the last 25 years.

The fundamental law which underlies the theory of the alternator and the transformer, is a convenient statement of these laws of electro-magnetic induction. The terms employed in this statement as we all know, bear a definite relation to the co-efficients of self and mutual induction, and these again depend in a perfectly well understood manner on the nature of the substances which form our magnetic field.

The laws of electro-magnetic induction have been verified by every electrical experiment of the last forty years. They are as true as any one of the physical laws known to us, and we see therefore that since the basis of the alternating current theory is an immediate inference from the general laws of electro-magnetic induction, that this basis is as firmly established as the basis of any other department of theoretical sciences.

Next we have to consider some of the most important consequences which have been deduced from the above fundamental relation. Let us take the simplest case; an alternator such as the one used by Joubert in his experiments. No iron in the armature coils, constant strength of the field magnets, constant speed of rotation. If the poles of the machines are not connected we get from our fundamental relation that the electro-motive force due to mutual induction between the magnetic field and the armature is equal to the impressed electro-motive force. Simple considerations lead us at once to the conclusion that the impressed electromotive force is a sine function of the time, its maximum value that is its amplitude depending on the strength of the field magnets, the speed of rotation and the construction of the armature coils.

Let us now connect the poles by a non-self-inductive resistance such as a series of lamps. A simple mathematical operation gives us complete account of the current generated. It is, just like the impressed electro-motive force, a sine function of the time, but its phase differs from that of the impressed E. M F. by an angle which increases with frequency and self induction, but diminishes with resistance. The relation between the current and electro-motive force is no more as simple as that given by Ohm's law. Instead of the resistance we have the *impedence.* In fact, as the reversals increase more and more the influence of the resistance upon the growth of the current becomes smaller and smaller, and in place of the effect of the resistance the effect of the co-efficient of self-induction forces itself into prominence. The *total electrical energy* produced in a unit of time is expressible in a great variety of ways. In terms of maximum impressed electro-motive force, impedance and resistance; or in terms of mean current and mean effective electro-motive force; or in terms of mean current, mean impressed electro-motive force and the cosine of the difference in phase, or again in terms of the square roots or the mean squares of the current, and of the impressed electro-motive force.

These relations between the total electrical energy produced and the other electrical quantities enable us to construct certain curves which suggest easy experimental methods of testing the truth of our deductions. These experiments were carried out by Joubert of Paris, Professor Stefan of Vienna, and Esson of England, and it was found that our theoretical inferences were completely verified. For full references consult Sylvanus Thomson: "Dynamo Electric Machinery," and a very excellent work of Professor Kittler, "Handbuch der Electro-Technik, Vol. II., Part 1."

This perfect agreement between theory and experiment will surprise no one who is acquainted with the working of Hughes induction balance, with experimental methods of determining the co efficients of self and mutual induction, and with the beautiful induction experiments of our learned ex-President, Professor Elihu Thomson. All these beautiful experimental designs are also inferences from our fundamental relation, inferences considerably more ingenious but also considerably less direct than the inferences which we have considered in the simple case just discussed.

We next consider the energy which is available in the external circuit. This is the part of the energy which is for sale, and it is well to inquire what means we have in determining the cost of production under conditions as simple as the above. If the conductors through which we send our current to the consumers have no self-induction, as is generally the case, the task is extremely easy. Simple analytical deductions from our fundamental law suggest the watt-meter, the electrometer, and a variety of other instruments whose indications depend either on the heating or on the magnetizing effect of the alternating current. With reference to this point we can consult several very excellent works like Grey's Electric Measurements, Ayrton and Perry's Practical Electricity and Kittler's Book.

Our methods of measurement in this simple case are exact deductions from an exact fundamental law and can be made in practice as exact as we choose to make them.

With reference to the watt-meter it is well to observe that under certain conditions, not at all difficult to realize in practice, it can measure the output of a machine even if the current does not follow the simple sine law. With regard to this point I refer you to investigations of Professor Stefen of Vienna, published in the reports of the Vienna Electrical Exhibition in 1883.

Let us now make the next important step in our discussion. We'll consider now the transformer under the following simple conditions: There are no Foucault currents nor hysteresis in the core of the transformer and the relation between the strength of the primary current and the mass of the iron core is such that the magnetization of the latter never approaches the saturation point. It seems desirable to work out this case analytically and at somewhat greater length.

Let L be the co-efficient of self-induction of the primary coil.
“ N “ “ “ “ secondary “
“ M “ “ mutual induction.
“ R “ resistance of the primary coil.
“ S “ “ “ secondary coil (both external and internal.)

Let x " current of the primary coil } at any moment.
" y " " " secondary " {

Our fundamental relation

$$(E_s)+(E_m)+(D)=(E_i)$$

will now be

$$L\frac{dx}{dt}+M\frac{dy}{dt}+Rx=E_0 \sin 2\pi z t \text{ for the primary coil.}$$

$$N\frac{dy}{dt}+M\frac{dx}{dt}+Sy=o \qquad \text{" secondary "}$$

E_0 is the amplitude of the electromotive force impressed by the alternator upon the poles of the primary coil of the transformer.

Our object is to express x and y in terms of the known quantities L, M, N, R, S and t. We proceed in exactly the same way as in the solution of simultaneous equations in Algebra We simply eliminate one of the unknown quantities, either x or y, and obtain a single equation containing only the other unknown quantity. Seeing that we have not a sufficient number of equations to do that we differentiate again and obtain two more equations, viz:—

$$L\frac{d^2x}{dt^2}+M\frac{d^2y}{dt^2}+R\frac{dx}{dt}=-2\pi z\, E_0 \cos 2\pi z t.$$

$$N\frac{d^2y}{dt^2}+M\frac{d^2x}{dt^2}+S\frac{dy}{dt}=o.$$

From these four equations we eliminate x and its differential coefficients and obtain, putting $2\pi z=p$.

$$(LN-M^4)\frac{d^2y}{dt^2}+(LS+NR)\frac{dy}{dt}+RSy=-p\,E_0\,M \cos pt. \quad (1)$$

This relation between the current in the secondary coil and the other quantities must subsist at every moment, and therefore also when $t=o$. We have then

$$(LN-M^2)\left[\frac{d^2y}{dt^2}\right]_0+(LS+NR)\left[\frac{dy}{dt}\right]_0+RS\,(y)_0 = -p\,E_0\,M \quad (2)$$

The suffix zero along the parenthesis denotes that the value of the quantity enclosed in the parenthesis is to be taken at the time zero.

To one dealing with abstract mathematical symbols equation (1) would present considerably serious difficulties of working out the details of his solution. But to you who are dealing with physical things, and to whom every symbol in equation (1) presents something that you have handled for years and years, you can put down the solution of (2) at once. Here it is

$$y = A_2 \sin 2\pi (zt - \varphi_2). \qquad (3)$$

The only thing that is unknown in this equation yet is the constant A_2. It is evident that it is some function of the constants L, M, N, R, S, E_o, p and t. We can determine it from equation (2) as we shall presently see. There is one point which I wish to emphasize particularly at this stage of our discussion, and that is the marked difference between abstract mathematical operations and those mathematical operations which are employed in the discussion of physical problems. The abstract mathematician is necessarily more or less indifferent to the physical meaning of his symbols; the mathemathical physicist is more fortunate. The physical meaning of his mathematical symbols makes his mathematical operations comparatively easy. Let our example illustrate this feature of mathematical physics.

Consider two telephones; one acting as a receiver and the other as a transmitter. We can construct and connect them in such a way, that they will resemble in every particular our example, namely the transformer in series with the alternator. In the case of these telephones the impressed electromotive force is a harmonic function of the time, the same harmonic function which describes the motion of the diaphragm plate of the transmitter. Now since in the receiving telephone we hear the same sound which is acting upon the diaphragm of the transmitter we conclude that the induced current which causes the vibrations of the diaphragm of the receiver is the same harmonic function as the impressed E. M. F. This induced current corresponds to our current y. Therefore, the secondary current of the transformer is the same function of time as the impressed E. M. F. This consideration enables us to put equation (2) down without going through all the mathematical steps which the pure mathematician would have been obliged to make before arriving at that equation.

(NOTE:—If the E. M. F. which the alternator supplies to the transformer had been of the form

$$\Sigma A_n \sin 2\pi znt + \Sigma B_n \cos 2\pi znt.$$

the induced current would evidently be of the form

$$y = \Sigma a_n \sin 2\pi (nzt - \varphi) + \Sigma C_n \cos 2\pi (nzt - \varphi)$$

where $\Sigma a_n \sin 2\pi znt$ stands for

$a_1 \sin 2\pi zt + a_2 \sin 4\pi zt + a_3 \sin 6\pi zt + - - - + a_n \sin {}^2\pi nzt$ and $a_1, a_2, - - - - a_n$ are constants to be determined in the same way as we are presently going to determine our constant A_2. The same remark applies to the other summation symbols.)

The determination of the constants A_2 and φ_2 is a simple algebraical operation. From (3) we have

$$(y)_o = - A_2 \sin 2\pi\varphi_2 \qquad \left[y \right]_{t=\frac{T}{4}} A_2 \cos 2\pi\varphi_2$$

$$\left[\frac{dy}{dt}\right]_o = p\, A_2 \cos 2\pi\varphi_2 \qquad \left[\frac{dy}{dt}\right]_{t=\frac{T}{4}} = p\, A_2 \sin 2\pi\varphi_2$$

$$\left[\frac{d^2y}{dt^2}\right]_o = p^2\, A_2 \sin 2\pi\varphi_2 \qquad \left[\frac{d^2y}{dt^2}\right]_{t=\frac{T}{4}} = -\, A_2 \operatorname{cor} 2\pi\varphi_2\, p^2$$

and therefore

$$A_2 \{[p\,(LN - M) - RS] \sin 2\pi\varphi_2 + p\,(LS + NR) \cos 2\pi\varphi_2\} = pME_o$$

or $A_2 \{a \sin 2\pi\varphi_2 + b \cos 2\pi\varphi_2\} = pME_o$, from (2_a)

$A_2 \, (a \cos 2\pi\varphi_2 - b \sin 2\pi\varphi_2) = o$ " (2_b)

The second of the last two equations gives $\tan 2\,\pi\,\varphi_2 = \frac{a}{b} = \frac{p^2\,(L\,N - M^2) - R\,S}{p\,(L\,S + R\,N)}$ From the first we get, considering that

$$\sin \pi\,\varphi_2 = \frac{a}{\sqrt{a^2 + b^2}},\ \cos 2\,\pi\,\varphi_2 = \frac{b}{\sqrt{a^2 + b^2}},$$

$$A_2 = \frac{p\,M\,E.}{\sqrt{a^2 + b^2}}.$$

$$\begin{aligned} a^2 + b^2 &= p^4\,(L^2\,N^2 - 2\,M^2\,L\,N + M^4) + 2\,p^2\,R\,S\,M^2 + R^2\,S^2 + p^2\,(L^2\,S^2 + R^2\,N^2) \\ &= p^2\,L^2\,(S^2 + p^2\,N^2) - 2\,p^4\,M^2\,L\,N + p^4\,M^4 + R^2\,(S^2 + p^2\,N^2) + 2\,p^2\,R\,S\,M) \\ &= p^2 \left[\frac{L - p^2\,M^2\,N}{S^2 + p^2\,N^2}\right]^2 (S^2 + p^2\,N^4) + \left[R + \frac{p^2\,M^2\,S^2}{S^2 + p^2\,N^4}\right]^2 \\ &\quad (S^2 + p^2\,N^2) \\ &\quad (S^2 + p^2\,N^2)\,(R_1^{\,2} + p^2\,L_1^{\,2}) \end{aligned}$$

Hence:

$$A_2 = \frac{p\,M\,E}{\sqrt{S^2 + p^2\,N^2}\,\sqrt{R_1^{\,2} + p^2\,L_1^{\,2}}}$$

Proceeding in exactly the same way, we get for the current in the primary winding:

$$x = \frac{E_0}{\sqrt{R_1^2 + p^2 L_1^2}} \sin 2\pi (zt - \varphi_1)$$

$$\text{Where } \tan 2\pi\varphi_1 = \frac{p L_1}{R_1}$$

This gives us a complete analytical solution of the ideal transformer. We can assume with perfect safety that the number of electrical engineers is very small indeed who will consider the analytical process through which we have just gone through as very difficult, and yet it is one of the most difficult mathematical processes which we meet in that part of the alternating current theory which I proposed to discuss, and which at the present time is of immediate interest to all practical engineers. You may, perhaps, ask: But what has this mathematical analysis to do with the practical aspects of the alternating current theory? Simply this: it bears upon the question whether the alternating current theory is or is not entirely within the reach of most of the electrical engineers, and this question is of eminently practical importance.

I considered the mathematical problem of the ideal transformer for the purpose of showing that its consideration does not involve any difficult mathematical operations, and not for the purpose of establishing and discussing the well-known relations between the various quantities which we just obtained. Any further consideration of the problem seems therefore superfluous.

The question of the efficiency and self-regulation in the case of a transformer of this kind is, as we all know, a very simple one, and can be answered at once from the above relations.

The *third point* which I proposed to consider was this: *What are the modifications which must be introduced into the relations so far obtained in order that our calculations should cover also conditions under which the alternator and the transformer are worked in practice.*

In order to get these practical conditions we have to drop one by one, several of the suppositions on which our calculations so far have been based. The first of the suppositions was that the effective magnetic field of our alternator was a simple harmonic one; the second suppositon was that the armature coils contained no iron. The immediate consequence of the removal of these two suppositions will be that the impressed electro-motive force of the alternator will no longer be a simple sine function but a more complicated harmonic function of the time. The same is true of the current, and it is evident from the remark made above in connection with the analytical consideration of the ideal transformer that the current will be expressible by a harmonic function of the same form as that for the impressed electro-motive force. Since the coefficients of induction are now much larger on account of the presence of iron in the armature coils the differences in phase between impressed electro-motive force and the current will be larger than without iron in the armature. Dropping now our third supposition that the magnetic permeability of iron is a constant quantity we infer that since for higher magnetizations this coefficient becomes smaller, that the differences in phase will be smaller than calculated for constant permeability. Dropping finally our last hypothesis, namely, that there are no Foucault currents or hysteresis we introduce a further modification into the values of our coefficient of induction and consequently also into the differences of phase. The same remarks apply to the transformer also. In what direction these modifications will effect the efficiency of our machinery is a question familiar to all of us. A complete general mathematical treatment of the alternator and the transformer is in the present condition of our knowledge of the magnetic properties of iron an impossibility; but fortunately for us such a treatment would also be more or less superfluous for practical purposes. Thanks to the profound investigations of Rowland, Hopkinson, Ewing, Wasburg, Bidwell, and others, we know just enough of the magnetic properties of iron to enable us to obtain a very approximate solution of the most general form of our problem. On this point we can consult the well known excellent investigations of Blakesley and Fleming and especially of Hopkinson, Kapp and Ferraris. The graphical methods of Blakesley and Kapp are very valuable. This solution of the general problem has been tested experimentally by Ferraris, Hopkinson, Ayrton and Perry and others and found to give a satisfactory account of the phenomena which actually take place in the practical working of the transformer. The very valuable experimental investigations of two member of this Institute, Dr. L Duncan of Johns Hopkins University, and Mr. Ryan of Cornell, we all know and appreciate; they afford us an excellent illustration of a fact which deserves a serious consideration on the part of every true electrical engineer, and that fact is that electricians whose methods of investigation show a perfect mastery of the theory can design and carry out experiments of eminently practical nature. The secret of it is that there is actually no real difference between the theoretical and the practical side of electricity.

As to the question of insulation of wires carrying high tension alternating currents, well, we know Sir W. Thomson's opinion on this point.

All these considerations which I could only point out here, but whose complete discussion can be easily gathered from the current electrical literature, seems to me to justify the following conclusion: *The generation and distribution of alternating current energy is based on as simple a theory as any other form of energy. The agreement between theory and practical experience is so perfect that the two form necessary supplements to each other. No difficulty was ever met in practice which the theory did not point out, and no difficulty which the theory can point out is beyond the reach of skilled practical engineers. There is therefore not the slightest ground on which objection could be be raised against the commercial use of this form of energy.*

THE PRESIDENT:—If there is no further discussion of this, we will pass to the next paper: "Magnetic Data of the Sprague Street Car Motor," by H. F. Parshall, of New York City, to be read by Mr. Crosby.

(Mr. Crosby read the paper.)

A paper read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.

MAGNETIC DATA OF THE SPRAGUE STREET CAR MOTOR.

BY H. F. PARSHALL.

Figures giving the ratios of the lines of force through various parts of the magnetic circuit to the lines of force through the armature have occasionally been fully published, the most noticeable being those given in a paper by Hopkinson some years ago. These ratios vary in the same type of dynamo or motor with any change of proportion; or, to put it in another way, in order that these ratios may remain constant in the same type, the ratios of the magnetizing force in the one part of the magnetic circuit to the magnetizing force in the other parts must also remain constant.

In making calculations on various motors made by the Sprague Company, I have found it necessary to confirm the assumed values of these ratios by measurements. It is the object of this paper to give the results of the measurements made on the street car motor, together with sufficient description, to make the values found of some use to those engaged in similar work. If I had had any intention of publishing these results, I would have endeavored to make them, in some ways, more complete than they now are, but so little detailed information exists on this subject, I have decided to give the result of my work up to date on this particular motor. The conditions under which this work has been carried on have not at all times been the most favorable for accuracy, but in the main, the results have been satisfactory.

Plate 1 shows the various peculiarities of the magnetic circuit, and gives dimensions of the several parts. The most noticeable points are:

The bell mouthing of the pole pieces shown in the section "A

B A." This bell mouthing greatly lessens the sparking, as does also cutting away of the tips of the pole pieces, as shown in "A B." With these modifications the brushes can be shifted an angle of 20 degrees without serious sparking.

The other noticeable points are the cast-iron side brackets, the width of the yoke and its comparative thinness.

The method of getting the ratio of the lines of force in one part to the lines of force in another was the usual one. Coils of a few turns were wound around these parts, and connected to a ballistic galvanometer, and when the needle was standing at zero, a known magnetizing force was suddenly reversed.

The galvanometer used was an Edelmann with a heavy ring form of needle very slightly damped. The deflections being small, it was assumed that the first throw was proportional to the induction through the measuring coil. The magnetizing coils were those commonly used on this motor.

Each coil was wound approximately to a depth of 4 centimeters, and along the cores 8.5 centimeters.

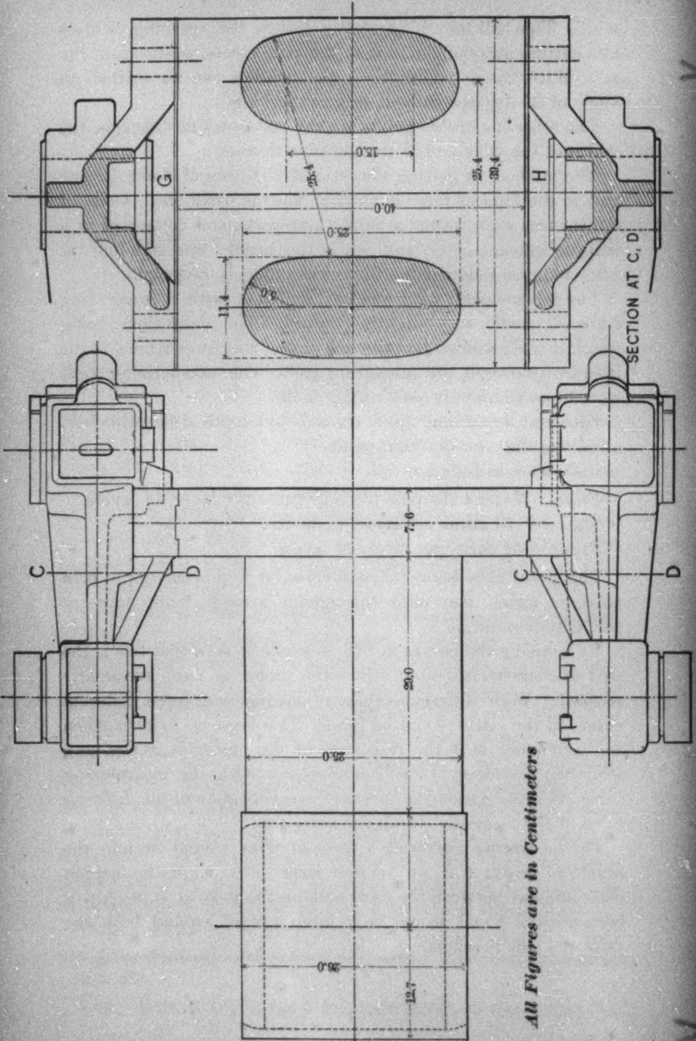
Coils were as follows:

FIRST. Nearest the pole piece 28 turns per layer, 11 layers.
SECOND. 31 turns per layer, 11 layers.
THIRD. 31 turns per layer, 13 layers.

This gives 2104 turns for both cores, or with a current of 6.75 ampéres, which was used throughout a magnetizing force of 14200 ampére turns.

By noticing the curves in Fig. 2 it will be seen that this is the part of characteristic upon which the motor is most frequently worked. With different values of magnetizing force, different values of the ratios would be found. This becomes evident when we remember that the resistance of the gap remains constant, while the resistance of the iron increases with the magnetizing force. For this reason the curves of magnetization of the *different* parts of the magnetic circuit are not given.

The measuring coils were 4 turns of wire wound around the armature core at E. F., on the pole piece; at A. B., on the magnet core, midway between the ends and on the yoke at G. H., had it been possible a coil would have been wound around both the yoke and side brackets.


G
H
15.0
25.4
25.4
30.4
40.0
25.0
11.4
5.0
SECTION AT C, D
C
D
C
D
7.6
20.0
25.0
25.0
12.7

All Figures are in Centimeters

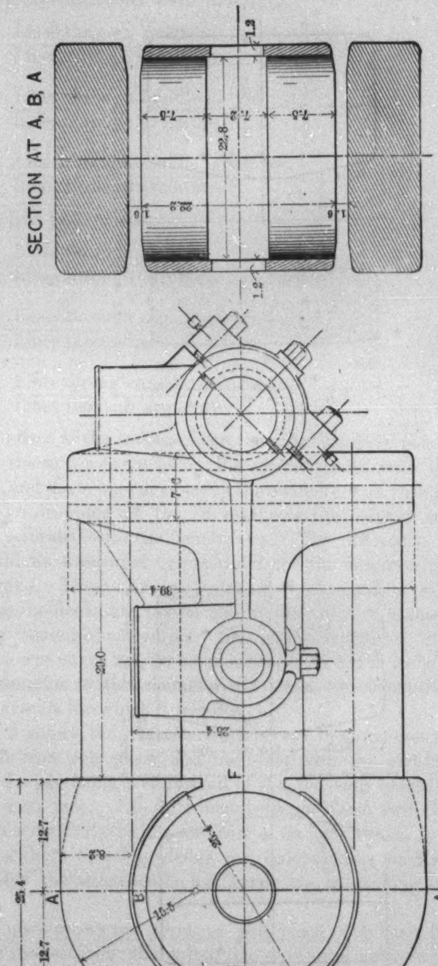

SECTION AT A, B, A
1.3
7.5
7.2
7.5
22.8
22.2
1.6
1.6
1.2
7.6
30.4
20.0
25.4
F
12.7
25.4
8.2
A
B
15.5
25.4
A
12.7
9.8
E
9.5
9.5

FIG. 1.—SPRAGUE STREET CAR MOTOR.

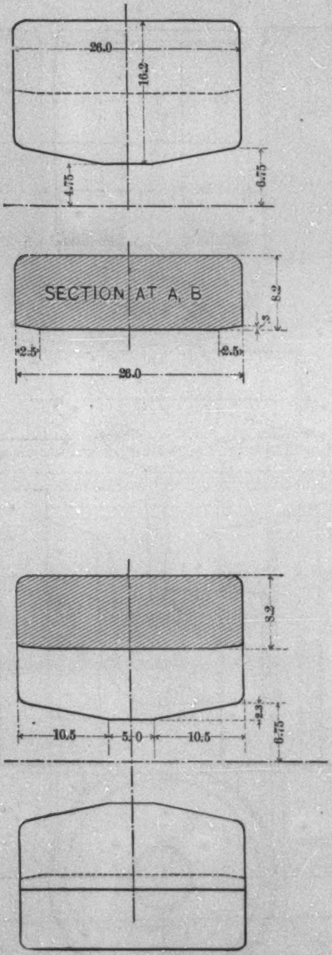

26.0
16.2
4.75
6.75
SECTION AT A, B
8.2
3
2.5
2.5
26.0
8.2
2.3
6.75
10.5
5.0
10.5

FIG. 1a—SPRAGUE STREET CAR MOTOR.

The following values were found:

$$\left.\frac{\text{Lines through magnet}}{\text{Lines through armature}}\right\}\ 1.45$$

$$\left.\frac{\text{Lines through middle of yoke}}{\text{Lines through armature}}\right\}\ 1.27$$

$$\left.\frac{\text{Lines through middle pole piece}}{\text{Lines through armature}}\right\}\ 0.666$$

Cast iron pole pieces.

$$\left.\frac{\text{Lines through magnet}}{\text{Lines through armature}}\right\}\ 1.52$$

$$\left.\frac{\text{Lines through middle of yoke}}{\text{Lines through armature}}\right\}\ 1.33$$

$$\left.\frac{\text{Lines through middle pole pieces}}{\text{Lines through armature}}\right\}\ 0.7$$

The effect of the leakage from the side brackets is shown in Fig. 2, the upper curve being the characteristic with them removed, and the lower curve being the characteristic with brackets on. The dropping of the curve shows the magnet cores are sooner saturated with the brackets on. The difference is small. It would be somewhat greater did not the brackets reinforce the yoke. These curves were first obtained by separately exciting the fields, and taking the number of revolutions, with a driving current of one ampére through the armature.

The lower curve has, by comparison, been found to be a close approximation to the characteristic when the armature is run with currents for which it was designed.

Fig. 3 shows the characteristics of two motors, one with the wrought-iron pole piece, and the other with the cast-iron pole piece, the gap being 2.85 instead of 3.2, the side brackets being on in each case. The difference between these two characteristics is somewhat striking, and carries its own lesson.

I wish here to acknowledge my indebtedness to Mr. G. J. Scott for the assistance he has given me in making measurements.

The plate shows two forms of pole piece; one has a full line. This is the cast iron; the dotted line shows the wrought iron pole piece.

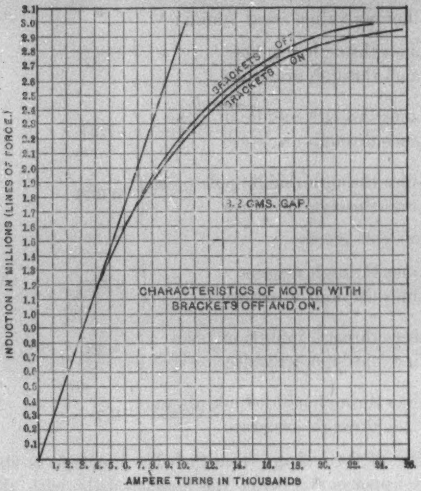

INDUCTION IN MILLIONS (LINES OF FORCE.)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 12. 14. 16. 18. 20. 22. 24. 26.
AMPERE TURNS IN THOUSANDS
BRACKETS OFF
BRACKETS ON
3.2 CMS. GAP.
CHARACTERISTICS OF MOTOR WITH
BRACKETS OFF AND ON.

Fig. 2

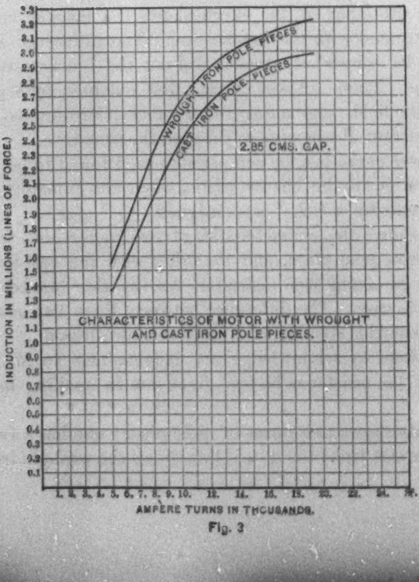

INDUCTION IN MILLIONS (LINES OF FORCE.)
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
2.6
2.7
2.8
2.9
3.0
3.1
3.2
3.3
1. 2. 3. 4. 5. 6. 7. 8. 9. 10. 12. 14. 16. 18. 20. 22. 24. 26.
AMPERE TURNS IN THOUSANDS.
WROUGHT IRON POLE PIECES
CAST IRON POLE-PIECES
2.85 CMS. GAP.
CHARACTERISTICS OF MOTOR WITH WROUGHT
AND CAST IRON POLE PIECES.

Fig. 3

DISCUSSION.

Dr. Louis Bell: It may be of some interest to know of the results to be obtained from the old type of Sprague motor. I had occasion recently to make tests on the old type of motor, and in that case the ratio between the number of lines passing through the armature and those in the field magnet was 1.65, but I found it was not a fixed quantity; that is, in motors taken apart and put together for the purpose of repairs. I doubt very much that they would be anywhere near constant for a year's service.

A paper read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.

THE INDUSTRIAL UTILIZATION OF THE COUNTER-ELECTROMOTIVE FORCE OF SELF INDUCTION.

BY THOMAS D. LOCKWOOD.

It may as well be confessed at the outset that although my production has cost me considerable thought, it does not claim to advance any original ideas. Its claims to attention are based solely upon its merits as a chronicle. There seems to be among the modern race of electricians not a few who regard that species of counter-electromotive force which is the subject of this paper, as being the only species in the genus. While of course this view is erroneous, it is easily accounted for by the notorious fact that the American Electrician as a class has little time to study. The fact, however, while it is indeed as I have termed it, "notorious," is still to be deplored; for it is certain that were electricians fully informed not only of the researches which took place before their own, together with the results of the said researches, whether these results took the form of success or failure, there would be much less valuable time wasted in supposed original research; there would be far fewer valueless inventions produced; and there would be a much smaller amount of subsequent vexations and useless litigation.

While counter-electromotive force, generally speaking, is a genus; the counter-electromotive force of self-induction is a species, and while an illustration of this statement will no doubt to most of us be an operation something in the nature of carrying coals to Newcastle, or water to the Mississippi valley, I cannot believe that it will be a waste of time, since doubtless we have many members who have not fully considered the subject.

Consider for a moment a definition of electromotive force.

What shall we say it is? It certainly is not a natural force like gravitation, and I do not think we can do better than concede that we call it a force, simply because it is convenient so to do; and define it as any agency tending to set up that form of motion or vibration which we call electricity; or if you please, any agency tending to the manifestation of electricity.

We are constantly hearing that a current of electricity is the result of a difference of potential between two points connected by a conductor, but though this statement through constant repetition has come to be as it were "human nature's daily food;" I am inclined to consider it as being after all but a mathematical way of saying that a current of electricity is the necessary result of an electromotive force provided with a closed conducting circuit. For it is the electromotive force which first determines the difference of potential, which therefore may be considered as being a kind of initial result. Following out this train of thought, it appears then that electromotive force is a function of the source or instrumentality which develops the current, and expresses the totality of difference of potential in the entire circuit; and while we may properly speak of the difference of potential, or fall of potential between any two points on the circuit, I think we can not with equal propriety speak of the E. M. F., in any other way than as something pertaining to the source.

And further consideration of the same idea, shows the incorrectness of the popular phrase often used of late years even by many eminent and able electricians, "a *current* of so many *volts*," the electromotive force being in no sense, near or remote, an attribute of the current.

To run counter to anything, is to run against it, to run in opposition to; to act opposedly; and so a "counter electromotive force" may be defined as any agency tending to develop a current of electricity in a circuit, opposite in direction to that of the current excited therein by the initial electromotive force.

A familiar instance is that of connecting up in an electric circuit a certain number of cells in opposition to a number of other cells. This constitutes a primary counter-electromotive force and its inclusion in the circuit reduces the current in two ways; first by reducing the acting electromotive force to a value equal only to the algebraic sum of two opposing forces; and secondly by adding internal resistance of the value of the cells added in opposition.

Another familiar illustration is found in that ingenious class of dynamo regulator, which acts by causing the opposing brushes to creep around the commutator and according to the work which is being done in the external circuit, to include in the circuit (by increasing or decreasing the lead of the brushes,) a greater or less number of armature coil sections exerting an electromotive force in opposition to the electromotive force which is developing the working current.

In these cases a utilization is made of counter-electromotive forces deliberately organized for the purpose, but they are not counter-electromotive forces due to self-induction.

At a very early period in the history of voltaic electricity it was discovered that there was some deteriorating force at work in every voltaic battery which depreciated the current to a much greater extent than exhaustion of the liquids or consumption of the solid elements could account for; and in 1801, Gautherot found[1] in this phenomenon which has foolishly been called "polarization," the germ of the secondary cell. He discovered that wires of platinum or of silver which had been used to decompose salt water acquired a power of themselves yielding a current when placed in acidulated water and could cause muscular contractions of a frog's leg and produce the galvanic test. And subsequently it was ascertained that the operation of a voltaic battery tended to coat the negative plate with hydrogen which tended to set up a counter-electromotive force between the hydrogen and the surface of said plate, which thus reduced the available energy of the battery, and that this action could be transferred to the electrodes of the same battery, if placed in a separate decomposing cell, and there tended to form electrically opposed surfaces which could themselves be used to develop a current in a direction opposite to that of the original current. As we all know, this operation long regarded only as an unmitigated evil, is now utilized in the formation and operation of cells adapted for the electrical storage of energy.

The counter-electromotive force of self-induction distinct from the foregoing, is that discovered by Professor Henry; and its most important use is that which has been mainly brought out in association with the employment of alternating or other currents for the purpose of regulation By reason of the fact that

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[1] See Izarn's Manual du Galvanisme, Paris, 1804, and Phil. Mag., 1806, Vol., XXIV. p. 185.

this utilization has proved to be overwhelmingly important, the electrical fraternity has partially lost sight of many earlier and contemporary instances of the useful employment of self-inductive electromotive force; which is indeed a close analogue in its character, mode of generation, and capabilities of use in regulation to that developed and utilized in the operation of electromotors.

Firstly—I desire to point out that though Henry was the first to study and discuss self-induction, he was not the first to notice its effects.

Until quite recently I, together with nearly everyone else, had supposed that the earliest published notice of this phenomenon was Henry's account [2] of his observation, published in 1832; but I have in my researches on the subject, dug out the fact that this is not so. I find that an experimentalist, Vassali-Eandi by name, records that [3] with a pole of fifty pairs he found that the fluid passed along a copper wire plated with silver, 1,151 feet in length, in a time incommensurable; the shock in this case was three times as strong as that experienced by immediately touching the two extremities of the pile.

The above isolated statement of facts stands I believe alone, and there is no record that it led to further research.

Henry on the contrary perseveringly pursued, and made himself master of the subject; and the record of his original observation, brief though it is, details the appearance of a vivid spark on the breaking of a battery circuit, if a wire thirty or forty feet in length be included in that circuit; shows that the effect is increased by coiling the insulated wire into a helix; and that the effect depends in some measure on the length and thickness of the wire. The note concludes with these remarkable words "I can account for these phenomena only by supposing the long wire to become charged with electricity which by its reaction on itself projects a spark when the connection is broken."

This, though brief, is then the first analytical notice of the electromotive force of self-induction, so long erroneously denominated after its result, the "extra current."

It is unfortunate that Prof. Henry did not for some time pursue the subject, and we do not hear from him again until March, 1835.

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[2] Silliman's American Journal of Science, July, 1832, Vol. XXII. pp. 403-8.

[3] Philosophical Magazine, Vol. XV. 1803; also Phil. Magazine, Vol. 3, 4th ser. 1852, p. 455.

Meanwhile his great contemporary, Faraday, had taken it up pursuant to an observation of one William Jenkin, and showed self-induction to be a corollary of his former masterly experimental researches in magneto-electro induction.

Faraday notes [4] the following points: "Self-induction exists in simply helices as well as in electro-magnets, though not to the same degree.

Helices are superior in developing induction to straight wires, and long wires to short ones.

Self-induction practically disappears when the conductor is permitted to inductively act upon a neighboring closed circuit.

That the amount of self-induction depends on the length of wire exposed to inductive action.

An iron core within helices, much exalts the action of self-induction.

The self-inductive effect depends not "upon a permanent state of the core, but on a change of state."

Henry now again takes the matter and in a consecutive series of papers, practically runs it to earth.

[5]In a paper of March, 1835, he gives more in detail some of the conditions of the development of self-induction. A long wire is better than a short one; a helix better than a straight wire of equal length. He also describes a shocking coil, and also a deflagration coil of but one wire in which self induction is involved.

[6]A little later he elucidates the origin and properties of self-induction and records that some additional energy appeared when iron was used as a core, but not much, because his coils were flat and not elongated helices. He ascribes all of these effects to dynamical induction, and shows that in a coil of a number of convolutions the convolutions act inductively on each other, and inferentially that the energy of the self-induction is the sum of that of the different coils.

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4. Experimental Researches in Electricity, Faraday, 1839, Vol. Ninth series, p. p. 332-343, read before the Royal Society, Jan'y 29, 1835. A series of notes "The Influence by Induction of an electric current on itself."

5. Journal of the Franklin Institute, March, 1835. Vol., XV. pp. 169-170, Sillimans American Journal of Science, July, 1836, Vol., XXVIII, pp. 327 and 331 and Scientific Writings of J. Henry, Washington, Vol. 1, pp. 87-91.

6. Transactions American Phil. Soc., N. S., Vol. V, pp. 223-231, reprinted in Sci. Writings, J. Henry, Washington. 1886, Vol., 1, pp. 92-100.

[7]In a third paper further experiments in self-induction or with the extra current, as it was then called, are discussed. We learn that the electromotive force of any self-induction coil within certain limits is dependent upon the length of the coil.

That the form of the coil has considerable influence on the intensity of the action. In the experiments of Dr. Faraday, a long cylindrical coil of thick copper wire inclosing a rod of soft iron was used.

This form produces the greatest effect when magnetic reaction is employed.

The "extra current" of self-induction developed in a coil, is controllable by the presence of an immediately adjacent independent coil. It is energetic when the circuit of the adjacent coil is open but absent when the adjacent circuit is closed."

Of course it is impossible in this paper even to indicate the many good things which are spread before the reader of the researches of both Faraday and Henry. They are well worth study, and in fact they laid a solid foundation for the work which is being done now.

Both discovery and invention are displayed in their work, much of which has only found its sphere of action within the last four years; for it is emphatically true as has been said by Mr. W. H. Preece, "that though we are accustomed to hear that necessity is the mother of invention, the child is as a matter of fact often born before its parent.

As is frequently the case with electrical discovery, self-induction was for long recognized, that is for the most part, and by the generality of electricians only as an unwelcome guest whose parting was to be speeded.

It was manifested mainly by an undesirable spark appearing upon the break of electric circuits in telegraphic, scientific and medical apparatus, and tending to burn away or oxidize, contact points; while in the case of the two wire induction coils its effect was to reduce the spark passing between the terminals of the secondary; and many have been the expedients, wise and otherwise, which were devised for its banishment. Many of these were patented; more were not; inasmuch as the fever for patenting everything from a solar system to a thought had not then come into fashion.

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[7] Transactions of American Phil. Soc. Vol. VI. pp 303–337, Nov. 2, 1838.
Silliman's American Journal of Sience, March, 1840, Vol. 38, pp. 209–243.
Scient. Writings of Joseph Henry, Washington, 1886, Vol. 1, p. 108.

Examples of this class of expedient are respectively:

British Patent, No. 12,772, September 20, 1849, granted to those old heroes of electric lighting history, Staite and Petrie, which has for its 18th clause, a mode of "preventing the spark when breaking contact in galvanic circuits. A thin platinum wire may still convey some portion of the current after the main circuit is broken, or a series of sufficiently long conductors may break contact one after the other." The preferred way, in plain English, was to connect a fine wire as a shunt round the break, and thus to furnish a closed circuit in which the self-induction circulated its current of breaking.

United States Patent, No. 33,269, granted to J. E. Smith, September 10, 1861, for a means of preventing the spark between the local points of a relay on breaking the circuit; shunting the break by a wire having two terminals dipping into a bottle of water.

Moreover as is well-known in the ordinary induction coil the action is emphasized by shunting the primary break by a condenser as first suggested by Fizeau[8].

This, as I shall point out later, is a real instance of the industrial utilization of self-induction.

Other early investigators in this line reduced the spark of breaking the circuit, by wire shunts also.

Although as I have stated, the recognitions of self-induction were mostly recognitions of an adversary, there were one or two early instances where the enemy was subjugated, and made to expend his energy usefully. The most notable instances of this are the single wire spark coils of Page and Callan[9] which were made especially with a view to exalt the self-inductive effects and with which metals were fused, and electrolytes were decomposed.

These were the forerunners of the spark coils used at the present day in electric gas lighting and comprising a single long coil wound to a suitable length upon a long core of iron wires.

There can, however, be no doubt that the principal attempts to make useful the counter-electromotive force of self-induction, and likewise the principal successes achieved, have been in the line of controlling, regulating or modifying the original, initiatory, or primary currents from which it has been developed.

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[8] Comptes Rendus, Vol. XXXVI. p. 418, 1853.

[9] Sturgeons Annals, Vol. 1, pp. 290–302.

I have compared this to the transposition of a given number of battery cells.

This analogy is however imperfect, since in cells of battery we may for the sake of argument regard the E. M. F., as being practically constant. Certainly they will in no sense regulate themselves in accordance with conditions automatically, but the inductive resistance *will* do this. For it is dependent for its efficiency as a generator, upon the strength of current flowing through it. Therefore, if the current through it due to the impressed electromotive force from any reason falls, the counter-electromotive force will also diminish and thus will permit a greater amount of the initial force to act; or in other words will permit the impressed energy to become more effective. Suppose we have in the main circuit of an alternating dynamo, supplying a number of incandescent lamps in bridges uniting its mains, an adjustable resistance; and suppose the inductive resistance, which we may also regard as a counter E. M. F. generator, to be initially adjusted, so that all of the lamps burn brightly; then within limits of considerable range, the current will be kept steady even though the applied E. M. F. fall or rise, or though the external resistance of the circuit be varied by lighting or extinguishing lamps.

For if lamps be extinguished and their branch circuits be opened, the external resistance rises and the current falls. It is true that the reduced current has not now so many branches to divide through, and that therefore self-regulation even without counter E. M. F. might be expected, but in systems of considerable magnitude it is not found to act practically, as well as it theoretically should. But here the useful effect of our self-induction regulation comes into play; and since the current acting upon the regulator is lowered, it is caused to develop a counter E. M. F. of less value, and thus to oppose less energetically the applied E. M. F, which therefore is brought to a greater extent into action, to overcome the increased resistance, and to maintain the normal current for the remaining work. So, if the applied potential falls, the current in consequence falls with it, and the counter E. M. F. developed falls also, and enables more of the applied E. M. F. to come into action. And the converse is true, if the current in the circuit from any other cause rises. Such an appliance would be still more convenient in connection with an arrangement of arc lamps fed by alternating currents, and connected up in parallel circuit, since the resistance of arc lamps would constantly be changing.

This has been so prominently brought before us by its most modern employment, namely by its well-nigh involuntary use in the distribution of electricity by means of alternating currents and transformers or converters having their primaries connected in parallel between the two mains of the source; and by the inductive resistance regulating device, patented by John Hopkinson, in England, August 3, 1881, No. 3,362; and in the United States, November 5, 1889, No. 414,541, that many persons have actually been led to believe that such use is really a new thing.

The employment in the regulation of electrical distribution, of counter-electromotive forces set up by the working currents themselves and proportioning themselves automatically to the work being done, is one of the most valuable and interesting features of modern electrical work; and, though such regulation requires to be supplemented by auxiliary arrangements, and though the belief of some that it could be attained absolutely without any waste has not been completely realized, still by availing ourselves of this feature we are enabled to control electricity with a facility and under conditions which otherwise would be unattainable.

The Hopkinson invention consisted in associating with an arc or glow electric light circuit employing alternating currents, a variable inductive resistance. This in one form was made by coiling a ribbon of thin sheet iron into a ring form, the different layers being separated by an insulating layer, and then by winding a number of coils of insulated wire on this ring, their adjacent ends being connected with plates between which contact plugs could be inserted, so that any number of the coils could be introduced or cut out from the circuit. Another form embodied the same principles, but had not a closed core. This form had a horse-shoe core made of an electromagnet formed of layers of sheet iron insulated from each other. The legs of the core are sorrounded with the coils, and the said core has an armature also made of insulated layers of sheet iron. In this form the armature is clamped down; but the regulability of the appliance is attained by moving the magnet core further into or withdrawing to a greater or less extent from the surrounding coils. The form first described, is in the British Patent shown as being included in circuit, with the two mains of a dynamo; incandescing lamps being in cross bridges between the said mains; while in another figure arc lamps are in parallel circuit with mains, an inductive resistance being included in each branch for each lamp and acting as an equalizer.

The iron core closed on itself to form a complete magnetic ring in which the lines of force are concentrated through the coil, and forced to cut all convolutions when exposed to reversals; the laminations at right angles to the currents, acting to facilitate magnetic change, to diminish hysteresis, and to prevent the circulation of eddy currents; and the insulation of the said laminations aiding in the latter function ; all tend to show that this is a very highly organized appliance and is not only well adapted to produce a very high degree of self-induction, but combines most of the best arrangements tending to that end, and it is therefore not surprising that its invention and use made a strong impression upon the electrical mind, and caused a revival of the idea that regulation on these lines was capable of being accomplished, to use the words of the patent, "without wasting energy." Without materially wasting energy would perhaps be more strictly accurate, for by its use a small amount of actual resistance coil is enabled to do the work of a very much larger amount.

I have certainly no desire to detract from the great merit of this application, but an honest chronicler has no choice and must say what has been done, and it must therefore be stated that inductive resistances and other self-induction appliances had long been used both experimentally and commercially; no doubt often with but an imperfect conception of their mode of operation.

[9] Poggendorff's researches into the action of induction coils disclose a remarkable state of affairs for so early a date These show that one induction coil was employed to send a current through the secondary helices of two others. The first coil thus acted as an alternating generator, and the two others as inductive resistances.

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9. Poggendorff's Annalen, Vol. XCIV., p 2 and London and Edinburgh and Dublin, Phil., Magazine, 1855, Vol. 10, 4th series. p. p., 136–137.

The primaries of two induction coils were connected in parallel and also in series at different times. When, to quote Poggendorf's own words: "Two instruments (induction coils) A and B, were so combined that the current traversed the two primary coils one after the other, the induction coils (secondaries) however were separated and A was allowed to give sparks, whilst B remained unclosed and without a soft iron core; the introduction of the latter into B, weakened the sparks of A, and the subsequent metallic closing of B reproduced their former strength."

The proper arrangement of induction coils is then discussed and whether the primaries should be connected in series or in parallel circuit. It is shown that the latter way is the proper one, and why. Then the paper goes on to say, "With respect to the cause of these phenomena it is no doubt to be sought in the extra or inner induction current. The outer induction current which is produced by breaking the inducing current has the same direction as the latter; whereas the extra current, which is at the same time excited in the induction wire, whose tendency is to weaken the first induction current, and the more so the stronger the extra current, which latter is especially strengthened by the soft iron core.

Consequently when the primary coils of A and B are connected one after the other, it is clear that the insertion of the soft iron core into that of B, will strengthen the extra current in that of A, and therefore weaken the induction current of the latter instrument.

By connecting the instruments side by side a closed circle is at once formed by them, and the extra current produced by the insertion of the soft iron core into B acts against that in A, and may therefore when both are equal completely neutralize it, when the outer induction current of A will necessarily be strengthened.

Without the circle formed by this combination, *i. e.*, in the wire leading back to the voltaic battery, the two extra currents act of course in the same direction and strengthen one another, in consequence of which the sparks at the current breaker are still very active."

These considerations of Poggendorff, show that even at this early period a great flash of light was thrown into the darkness which hitherto had obscured the reactions of self-induction, and though we have largely failed to use that light until quite recently, this is chiefly attributable to the same oft recurring reason, that there was really little call for it; hence it was soon hid under the bushel of the results of research on other subjects of more immediate interest.

The statement which I last quoted, brings me again to the application by Fizeau of the condenser as a shunt to the vibratory break, and to its operation.

[10]As shown by Lord Rayleigh, the condenser operates by producing electrical oscillations and in its action the spark at the contact breaker is greatly decreased and the spark between the secondary terminals greatly magnified, because at the break the condenser is virtually an inductive reservoir, being an electrostatic shunt. And being an electrostatic shunt, the energy it momentarily absorbs is returned reversely to the primary circuit, just as in the discharge of a secondary cell, and increases the inductive variation in the secondary circuit during the brief period of time immediately after the break. And as the electromotive force in the secondary is thus exalted it is not difficult to see why the condenser increases the sparking distance.

As early as December 6, 1862, a patent for cable working, No. 3,453, was taken out by C. F. Varley, which describes the use of a self-induction resistance. This patent says, "A second circuit from the cable to the earth independent of the receiving instrument is formed by means of a resistance coil with a large iron core. It may be advisable to connect the cable to earth through an induction coil consisting of a large bundle of iron wire, surrounded by a long length of fine wire, the action of which is as follows: On reversing the battery connections the induction plates (condenser) and battery combined, send a short impulse into the cable, which divides; one portion into the cable, the other through the induction coil to the earth. At the first moment, the iron of the core opposes the passage of the current, consequently during the first instant of time, nearly the whole force of the current is applied to the cable. As the iron becomes magnetized to its maximum, this opposition ceases, but the plates have been charged in the opposite direction, and there is no longer any current passing from them into the cable to maintain the magnetization of the iron; the demagnetization of which, induces a current in the coil, and discharges the cable. In this way each impulse is followed by a short impulse in the opposite direction.

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[10] Phil. Mag. Vol. XXXIX., p. 428, et seq.

One of the figures of the patent, shows that the wires of the core are made long, and are turned back on all sides over the wire of the coil, so as to entirely encase it. This feature was in conformity with a previous British Patent, No. 3059 of 1856. The arrangement however clearly shows a use of a self-induction coil as a current controller, and indicates the function of a large iron core.

We next find the counter E. M. F. of self-induction coming into use in connection with fast telegraph systems. Arrangements for its use are shown in the United States Patents granted to Mr. Edison. These are respectively, No. 135,531 of February 4, 1873; No. 141,773 of August 12, 1873 and No. 147,313 of February 10, 1874.

The first and second disclose a shunt circuit including an electro-magnet connected round the receiving instrument of a chemical telegraph. The first, also shows a leak to earth from the line, which leak includes an electro-magnet. In both cases the object is to utilize the discharge current developed by the electro-magnet in the regulation of the operation and to produce sharp and clear signals.

The third, describes the use of electro-magnets in shunt circuits round the transmitting and receiving instruments of an automatic telegraph system and is said to be an improvement on the first. A number of electro-magnets are shown and by means of a switch one or more of these may be introduced. In other words the inductive resistance is here adjustable, and is operated by breaks, not by reversals.

British Patent No. 3,935, Nov. 14, 1874, to Alexander Melville Clark for a chemical copying telegraph, uses induction and other coils to clear a line by the self-inductive counter E. M. F. By the decrement or cessation of the impulse, (as the patent states) the strongest depolarizing effects are produced, and the line is successfully cleared.

Next come four other patents to Thos. A. Edison. These are U. S. Patent, No. 168,243, of Sept. 28, 1875, for an automatic telegraph. This, as in the previous cases, employs an electro-magnetic shunt.

U. S. Patent, No. 168,385, of October 5, 1875, Duplex Telegraph. This is an excellent example of self-inductive regulation. The counter E. M. F. is developed from electro-magnets in a changing electric circuit, and the coils have cores closed on themselves.

The next two, No. 173,718, of February 22, 1876, for automatic telegraphy; and No. 178,221, May 30, 1876; Duplex Telegraphy; involve no new principles and are like the preceding ones.

[11]Much information regarding the subject and further examples of its practical application can be found in a particularly able paper on "Shunts," read by William H. Preece, before the Society of Telegraph Engineers in 1887. The subject of the counter E. M. F. developed in electro-magnets is discussed, and the increase of the same, when the iron core is endless, is determined and pointed out; a good many instances of the practical uses of the self-induction shunt are described.

U. S. Patent, No. 207,724, of September 3, 1878; granted to Thos. A. Edison for a Duplex Telegraph, shows an electro-magnetic coil and closed magnetic circuit core placed in each branch of a Wheatstone Bridge duplex telegraph, to counteract by its counter E. M. F. of self-induction the discharge of the electro-magnets in the bridge circuit. In Culley's Handbook of Practical Telegraphy, London, 1878, p. p. 303 to 304, also p. p. 305 and 411 the regulation of currents by inductive resistances is considered.

In the first instance, the counter E. M. F. of an adjustable series of electro-magnetic coils is used to delay the discharge of a condenser in a duplex system. This is closely analogous to the function of the Hopkinson device, and is very suggestive. The reference on page 305 states that "static discharge can be entirely compensated for by the use of an induction coil, or a series of electro-magnets instead of a condenser."

U. S. Patent, No. 227,039, of April 27, 1880, to Muirhead and Winter, for a Quadruplex Telegraph, describes electro-magnetic shunts for reversing keys and relays, which are to counteract by their discharges electrostatic retardation. The specification says, "The electro-magnets may be of the well-known closed horseshoe form, or they may consist of a single rod of soft iron with flanges of soft iron and a cylindrical casing of iron closing over the wire and connecting magnetically flange with flange.

U. S. Patent 231,904, September 7, 1880, to Joseph E. Fenn, Duplex Telegraph, uses an electro-magnetic generator of counter E. M. F. in the line circuit to counteract effects of discharge. It is made with a closed magnetic circuit, a separate coil being on each leg of a multiple pole core; several of these poles are made with yokes, and the combined yokes can be made magnetically continuous or discontinuous at will by means of iron plugs which can unite the different sections of core.

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[11] Journal of Society of Teleg. Engineers, London 1877, p. p. 40-69.

A book published in 1880, by Louis Schwendler, and entitled, "Instructions for testing telegraph lines, and the Technical Arrangements of Circuits," Vol. 2, p. p. 144-147, gives a description of an electro-magnetic shunt and its operation. It is made like an ordinary electro-magnet, but has an adjustable wedge-shaped armature in contact with the cores. This of course operates by utilizing the counter E. M. F. of self-induction which develops currents that circulate through the shunt, and sharpen the signals.

In telephony also, as in other fast systems employing rhythmical currents, the counter E. M. F. has by no means been idle. As in telegraphy our early acquaintance with it was an unpleasant one. Many of the earlier telephone lines connected with a number of stations, and at each station there was of course an electro-magnet to operate the call. In some cases this was a telegraph relay, and in other cases a bell magnet. But in either case it was found, as indeed might have been anticipated, that the telephone currents had a decided repugnance to pass through the intervening electro-magnets on their way from one station to the other. To quote the graphic words of one of the patentees of devices intended as remedies for this trouble, it was found that electro-magnets were to a large extent "opaque to telephone currents."

Of course this is due to self induction. The resistance of the line or the magnet coils had little or nothing to do with it. The convolutions however had, since it is clear that the electromotive force of the self-induction was proportional within certain limits to the number of convolutions.

The same difficulty appeared also in exchange work, where between any two connected lines was interposed an annunciator, to give from either end station a disconnecting signal. Several devices have been suggested for the removal of this difficulty and some of them have been patented.

Elisha Gray shunts the several interposed magnets by condensers: vide United States Patent, 203,264, of May 7, 1878.

F. W. Jones, attacking the same difficulty, shunts the interposed magnet by a non-inductive resistance controlled by the armature of the signaling magnet. See United States Patents, 238,399, of March 1, 1881, and 238,912, of March 15, 1881.

Other devices have also acted to shunt the bell or annunciator magnets in different ways; and still other suggestions have been, to surround the iron core with a brass sleeve, or with a closed circuit consisting of one layer of insulated wire; but these last, while certainly reducing the retardation, reduce also the magnetic power of the appliance. And there is no remedy so effectual as the absence of the interposed electro-magnet.

The service rendered by self-induction in telephony, and that which still may be expected, fortunately will probably outweigh the ills which it introduces. In many switchboard installations for metallic circuits, the supervising telephones are looped or bridged across between the two conducting links which unite one of the two metallic circuits with the other, and their self-induction prevents a material loss of current. Where from some condition of the service such for example as the requirement of supervising both metallic and earth return circuits at the same switchboard it sometimes becomes necessary in bridging the telephones to attach an earth branch to the connecting link on one side of the instruments; in this case it has also been found necessary in practice to place coils containing iron cores on the other side of the earth branch, so that not only the resistance but also the self-induction may be balanced.

It has also been ascertained that many telephones can at different stations be placed across from one wire to the other of a metallic circuit without any perceptible diminution of the effect at any one of them. This is one of the most important results of self-regulating attribute of self-induction.

Perhaps, however, the most valuable instance of turning an electrical enemy into an electrical ally, is the way in which by the proper use, construction and arrangement of electro-magnets, a plurality of either telephonic or partially telephonic and partly telegraphic messages may be transmitted over the same circuit at the same time.

The pioneer in this kind of work was C. F. Varley, who as early as 1870 took out a patent, No. 1,044 in England, for a combined simultaneous ordinary Morse and harmonic Morse transmission over the same wire; in this system the straight Morse was worked through electro-magnets, while the harmonic branches were led off from the main line from points outside of the electro-magnets.

Carrying on this line of invention, Mr. Van Rysselberghe of

Belgium, and Dr. Rosebrugh of Toronto, Canada, have worked out systems whereby telegraphy and speaking telephony can be at the same time operated over the same circuit.

Since, however, there is enough in either system to fill up a paper devoted to them exclusively, and since this paper is already too long, I find it impossible here to describe them in detail, reserving this possibly for some future occasion.

Self-induction has also been caused to aid in eliminating the disturbing results of extraneous induction caused by parallel circuits, as in the United States Patent of Mr. Edison, No. 203,019, of April 30, 1878, where a telephone circuit is freed from external influences by combining it with an induction coil connected with the disturbing circuits in such a manner that the direct disturbances received in virtue of the parallelism of the contiguous circuits is neutralized by an equal and opposite induction received also from them through the induction coil. This, however, is not a practical expedient.

Closely analogous to the self-inductive regulation of which I have been speaking, is that upon which the efficiency of an electro-motor depends. This was first observed by Jacobi[12] who says:

"Experimenting on the magnetic force of a bar of soft iron, I sometimes found considerable differences for which I could in no way account. I was curious to know if these differences proceeded from the nature of the iron, or from the weakening of the electric current produced by a voltaic pair of half a foot square of surface. For this reason, I placed in the circuit, a galvanometer so distant as not to be affected by the direct magnetism of the bar. I was much astonished to see the needle recoil on placing the armature and advance on removing it, for it was the first time I had known the double quality of the connecting wire, viz., that of constructing the voltaic current, and at the same time representing an ordinary wire subject to the action of a magnet in motion. The spiral producing a magnet by the voltaic current is at the same time a magnetic electrical spiral in which a magnet is placed.

Hence the solution of the uniform velocity of the magnetic machine. For being set in motion by the magnetizing power of a voltaic current it represents simultaneously an apparatus composed of magnets in motion and capable of producing a magnetic electrical current in a direction opposite to that of the voltaic current."

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[12] Sturgeon's Annals of El'y, 1837, Vol, 1, pp. 408–419.

Jacobi in a subsequent paper, practically elucidated the principles of the operation of counter E. M. F. in electro motors, even as now understood, although he possibly did not state them as we now would. But he clearly showed that a motor may be regarded as a dynamo acting to develop an electromotive force, opposite in direction to that acting upon it, E. That the resultant force was of course E-e, and that this together with the resistance of circuit determine the strength of the current. That the motor utilizes C e of the electrical power supplied C E; and he furthermore showed that the power developed by the motor C e, is at its maximum when e equals one half E.

It may be thought by some that considering the title of the paper the principal utilization to which I have referred, viz., the use in regulation of systems of alternating currents operating converters should have been discussed. It does not seem to me that it is necessary; this has often been done, and will again often be done by others much more competent than myself to handle the subject. But it does seem right that one should be found to give due credit for those who in the same line of thought are "not lost, but gone before," and I am glad that I am in a position so to do.

There seems little need for me to cite any more instances, showing that like nearly all new arts, the art of regulation by means of self-induction and of otherwise usefully employing the counter E. M. F. due thereto, is not *quite* new, and that while we can congratulate ourselves upon the achievements of the present, we should not fail to respect the foundation layers of the past, for of a truth, there were giants in those days.

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